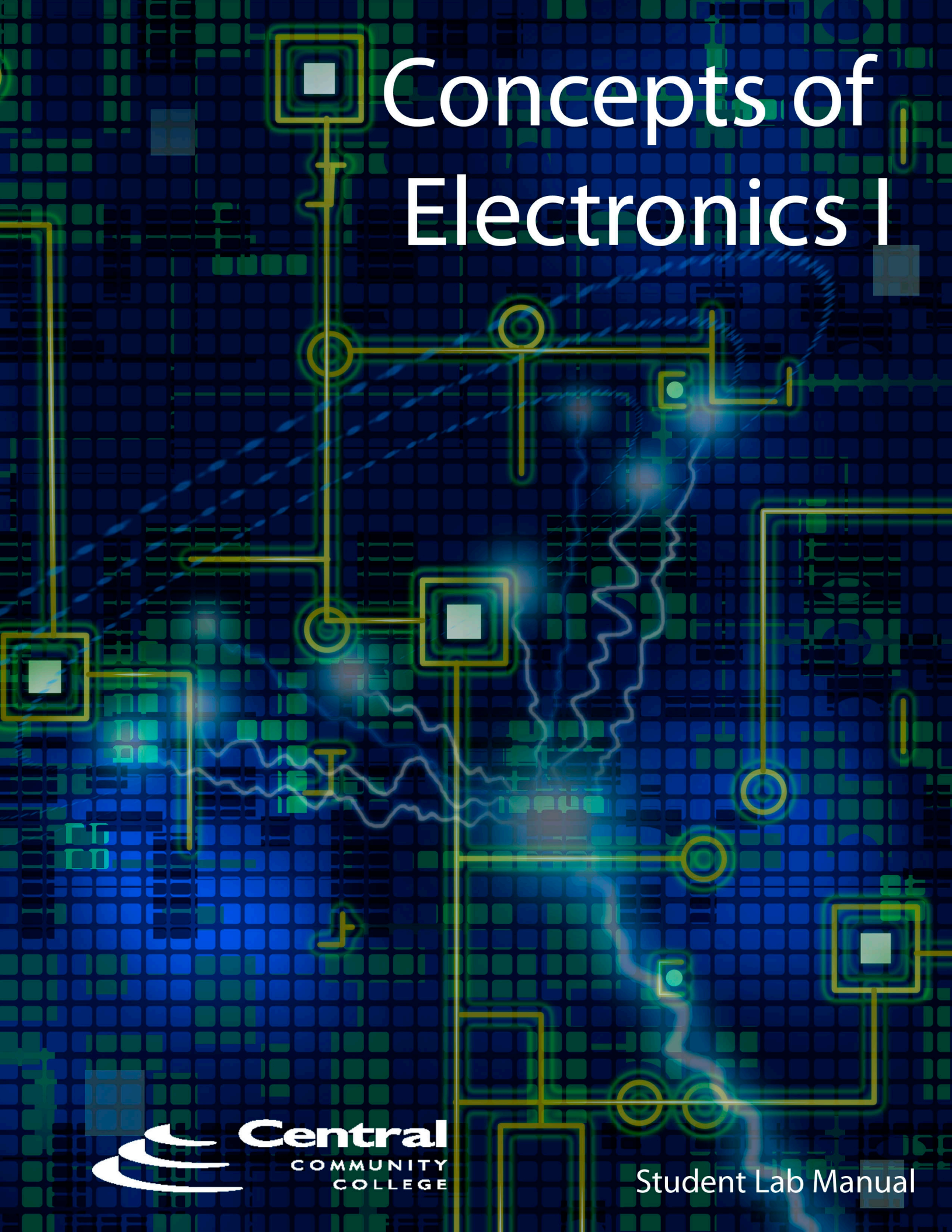
Concepts of Electronics I



Central COMMUNITY COLLEGE

Student Lab Manual

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Introduction

The purpose of this lab book is to provide hands-on experience to reinforce the electronic theory data learned in this course. Students will improve their critical thinking skills by connecting circuits from schematics, making measurements with a digital multimeter, organizing data, and analyzing observations.

Most of the projects in this lab manual promote understanding of the intended points made by performing calculations and making measurements. The results are then compared and conclusions are drawn at optimum times during the project.

The projects in this lab manual are designed to help students develop and improve their abilities to:

- Follow instructions carefully.
- Make accurate measurements and calculations.
- Analyze technical data appropriately.
- Draw logical conclusions from their observations and calculations.

When performing each lab experiment make sure the meter and test instruments are set to the correct function and range to ensure an accurate meter reading. There are also many calculations and measurements in these lab projects that will require rounding of decimal points. To ensure a correct answer, make sure each number is rounded to the nearest hundredth (two decimal places). For example, if an answer calculates to 3.457 mA, the correct answer would be 3.46 mA. If an answer calculates to 21.3523 kΩ, the correct answer would be 21.35 kΩ. If the answer is a whole number or if the hundredths place is a zero, the extra zeros do not need to be added. For example, an answer of 10 volts does not need to be written as 10.00 V.

The answers must also be written in metric prefix form with the correct unit label. For example an answer of 11270 Ω should be written as 11.27 kΩ. An answer of .482 A should be written as 482 mA, etc.

For your convenience the Ohm's Law formulas have been added toward the back of this lab manual. Also included is an instructor sign-off sheet. Have your instructor initial and date this sheet in the appropriate location when the corresponding project is correct and complete. This will help both you and your instructor track your progress throughout the experiments.

We wish you great success during these hands-on experiences and hope that this manual will be both interesting and educational as you prepare to enter the technical world of electronics.

Equipment

- Elenco XK-700 electrical trainer
- Multi-range digital multi-meter (DMM)
- Breadboard jumper wires
- Testing jig (Used for troubleshooting exercises)
- AA battery holder with leads
- AA battery

Components

- Resistors
    - 1 kΩ, carbon film, 1 watt, 5% tolerance
    - 3.3 kΩ, carbon film, 1 watt, 5% tolerance
    - 4.7 kΩ, carbon film, 1 watt, 5% tolerance
    - 6.2 kΩ, carbon film, 1 watt, 5% tolerance
    - 10 kΩ, carbon film, 1 watt, 5% tolerance (4)
    - 18 kΩ, carbon film, 1 watt, 5% tolerance
    - 47 kΩ, carbon film, 1 watt, 5% tolerance (2)
    - 100 kΩ, carbon film, 1 watt, 5% tolerance
    - 220 kΩ, carbon film, 1 watt, 5% tolerance

    - 11 Ω, carbon film, 1/2 watt, 5% tolerance
    - 2 kΩ, carbon film, 1/2 watt, 5% tolerance
    - 300 kΩ, carbon film, 1/2 watt, 5% tolerance
    - 10 MΩ, carbon film, 1/2 watt, 5% tolerance

    - 150 Ω, carbon film, 1/4 watt, 5% tolerance
    - 5.6 kΩ, carbon film, 1/4 watt, 5% tolerance

    - 1.2 kΩ, carbon film, 1/8 watt, 5% tolerance
    - 39 kΩ, carbon film, 1/4 watt, 5% tolerance

    - 270 kΩ, metal oxide, 2 watt, 5% tolerance

    - 2.2 kΩ, carbon composition, 1/2 watt, 5% tolerance
    - 750 kΩ, carbon composition, 1/2 watt, 5% tolerance

Digital Multimeters

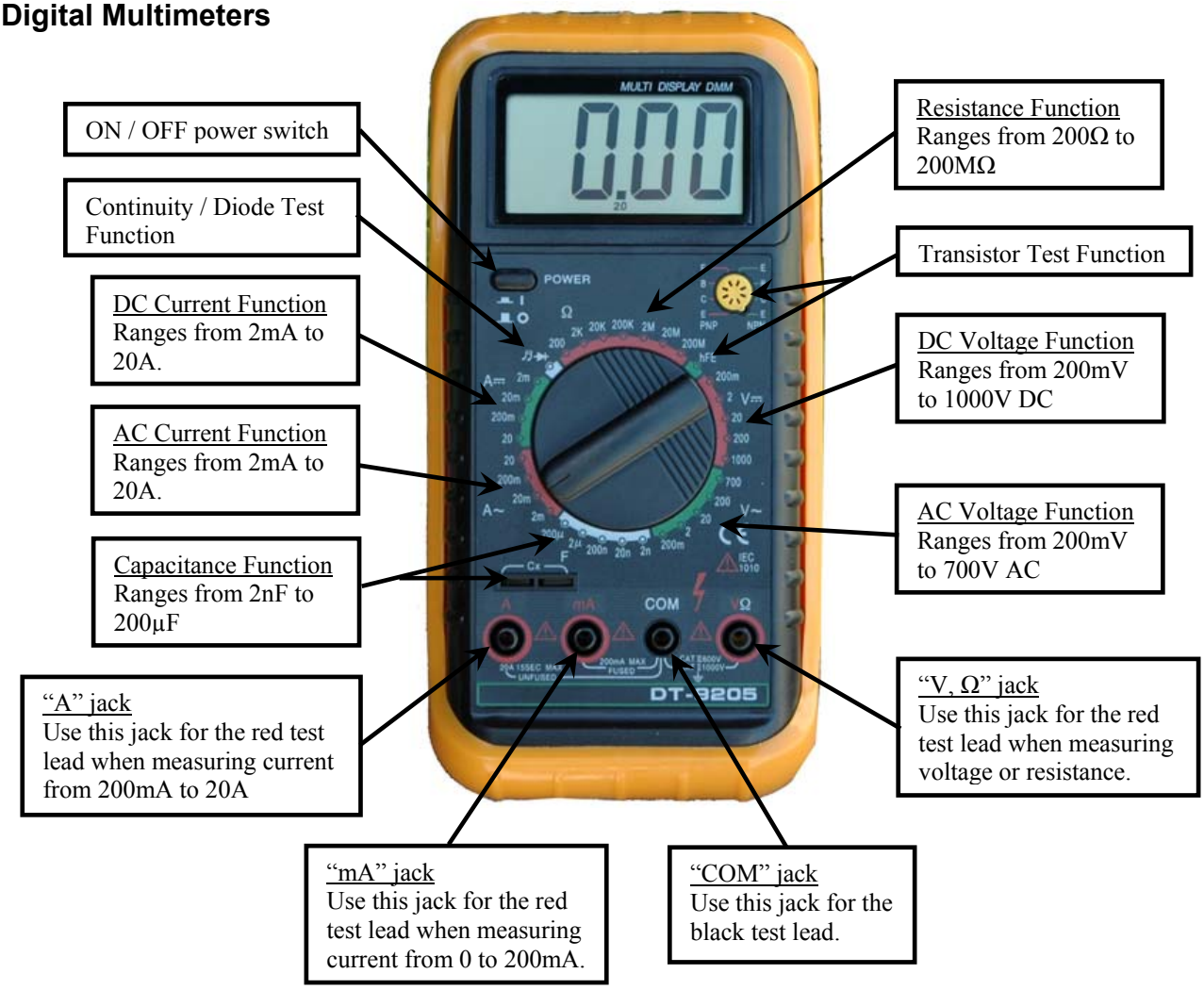

ON / OFF power switch
Continuity / Diode Test Function
DC Current Function
Ranges from 2mA to 20A.
AC Current Function
Ranges from 2mA to 20A.
Capacitance Function
Ranges from 2nF to 200µF
"A" jack
Use this jack for the red test lead when measuring current from 200mA to 20A
"mA" jack
Use this jack for the red test lead when measuring current from 0 to 200mA.
"COM" jack
Use this jack for the black test lead.
Resistance Function
Ranges from 200Ω to 200MΩ
Transistor Test Function
DC Voltage Function
Ranges from 200mV to 1000V DC
AC Voltage Function
Ranges from 200mV to 700V AC
"V, Ω" jack
Use this jack for the red test lead when measuring voltage or resistance.
MULTI DISPLAY DMM
POWER
COM
DT-9205

Figure P-1

Multimeters are very useful test instruments. By operating a multi-position switch on the meter they can be quickly and easily set to be used as a **voltmeter**, an **ammeter** or an **ohmmeter**. Some meters have additional features used to measure capacitance and frequency as well. They have several settings called "ranges" for each type of meter and the choice of either alternating or direct current measurements.

Voltmeter

To test for voltage, first determine whether the application you're testing uses AC or DC voltage. Then set the dial to the appropriate function and plug the red test lead into the correct jack used to measure voltage.

Like all test procedures, when testing voltage, set the meter to the range just higher than the expected voltage and decrement it down as needed to increase the accuracy of the reading. If you don't know the expected range, set the range to the highest one available. Take the black test lead and place it on the negative polarity point of the circuit you want to measure. The red test lead will go on the more positive polarity point. When measuring voltage, the test leads of the meter must always be connected in **parallel** or "across" the component or circuit to be measured as in Figure P-2 on the next page.

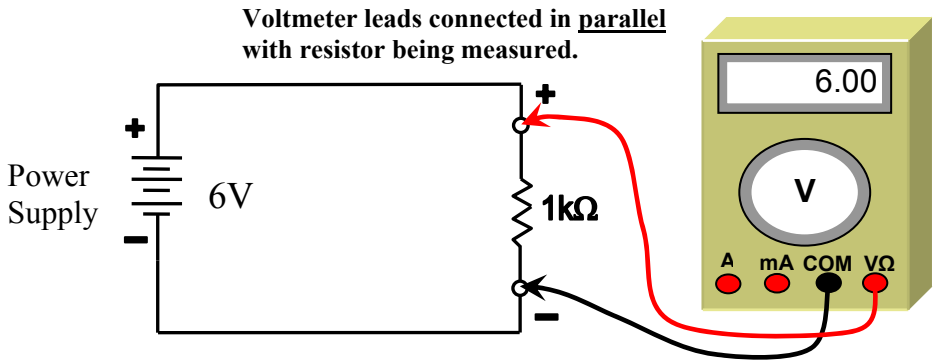


Figure P-2

Ammeter

To measure current, break the circuit where you want to take the reading. Set the meter to AC or DC current depending on the source being tested. Plug the test lead into the correct jack to measure the expected current.

Note: Most meters have a separate jack that needs to be used to measure current from 0 to 200mA and from 200mA to 10A or sometimes 20A.

Insert the meter in **series** or "in line" with the circuit to be measured by placing the red test lead on the positive polarity point and the black lead on the negative polarity point (see Figure P-3). Similar to the voltage, the correct current range needs to be selected. Start by selecting the next range higher than the expected reading. If the meter ever reads "0" when an actual reading should be present, check the fuse for the 200mA port.

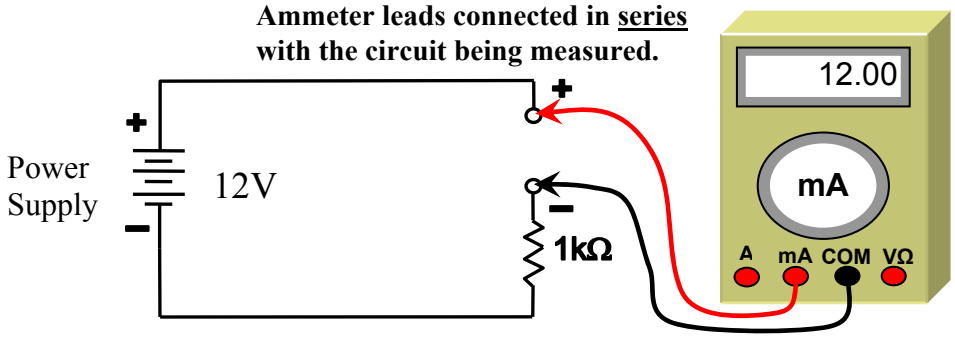


Figure P-3

Ohmmeter

To test for resistance, first remove the power from the circuit component to be tested. This prevents the meter from becoming damaged by the source. After ensuring that all power is off, set the dial to the resistance function. Select the appropriate range on the dial. Remove the component to be measured from the circuit (This prevents false readings from any other components in the circuit). Make sure the test leads are plugged into the correct jack to measure resistance. Connect your test leads to the component and take the reading.

It's important that you have good contact between the test leads and the component being tested. Dirt, oil and poor test lead connection can undesirably alter resistance readings.

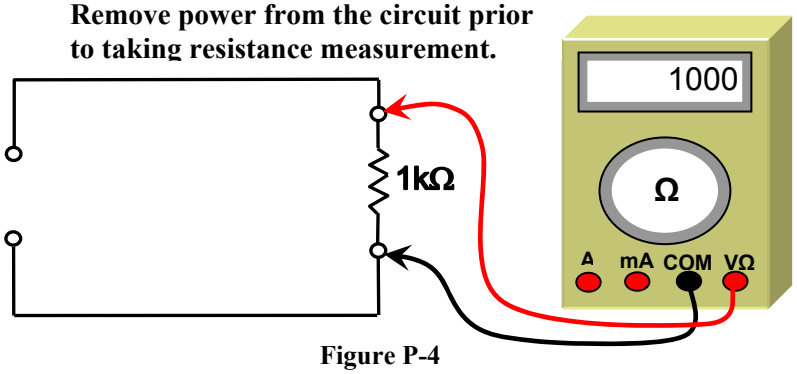


Figure P-4

The Elenco XK-700 Electronic Trainer

This guide will explain the basic operations and features of the Elenco electronic trainer that you will be using for the majority of the lab experiments in this course. Please take a few minutes to read through this guide and study the illustrations so you will become familiar with the different functions of this trainer.

In this user guide you will identify the five main sections of the trainer. You will also learn the purpose and the function of each section.

The five sections of this trainer are listed below. See Figure P-5 for a pictorial diagram of the trainer.

1. Power supply section
2. Variable resistance section
3. Function generator
4. Digital section
5. Breadboard section

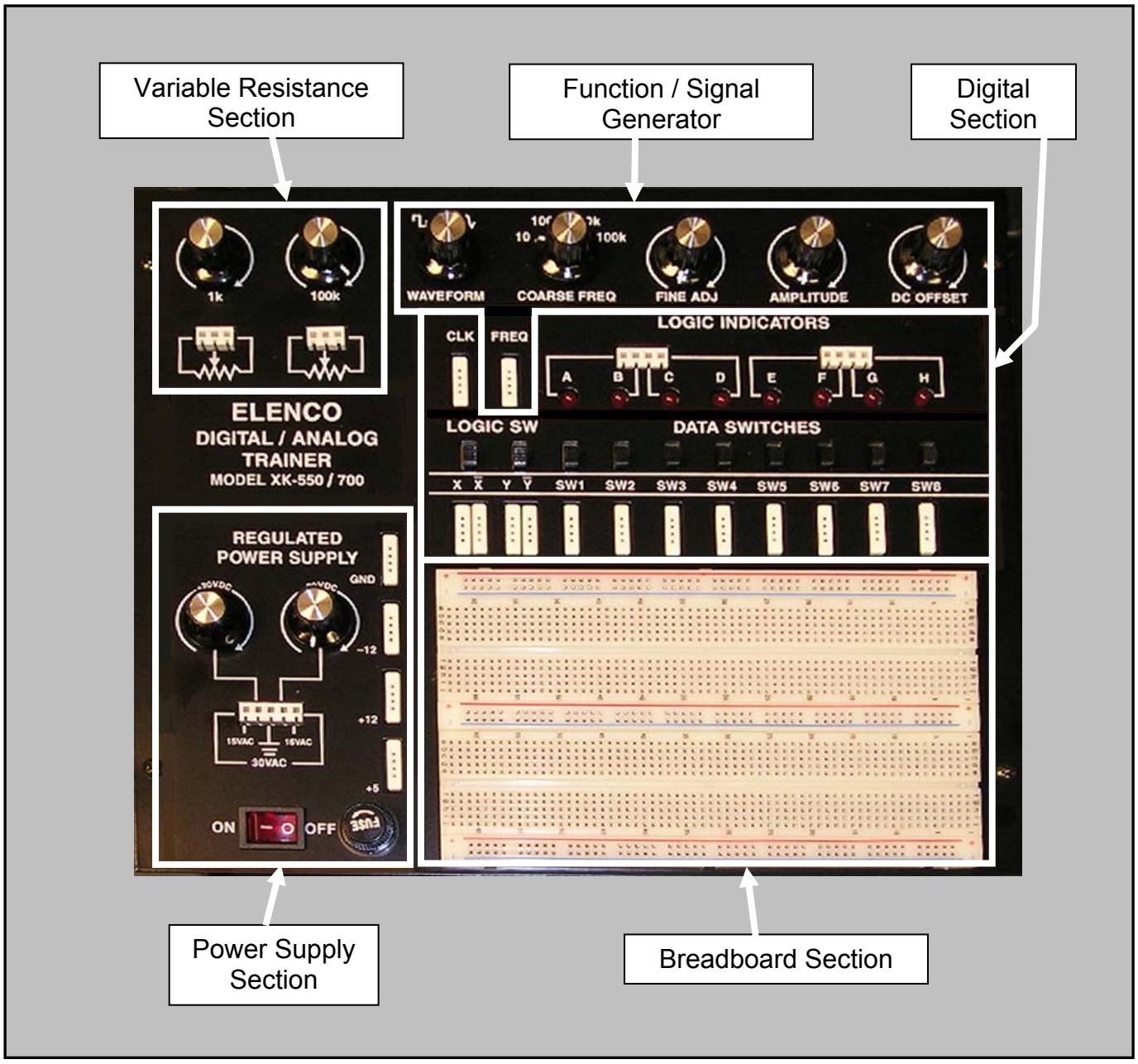


Figure P-5

Power Supply

The Elenco trainer has several built in DC power supplies to satisfy most electronic design needs.

The two variable DC power supplies produce up to +20 volts and -20 volts at 500 milliamps. Below 15v the available current is over 1 amp.

Three fixed power supplies produce +12vdc, -12vdc, or +5vdc at 1 amp each.

All of the power supplies are regulated to within 150 millivolts. In other words, if you increase the current draw from no load to 500 milliamps, the voltage will change less than 150 millivolts.

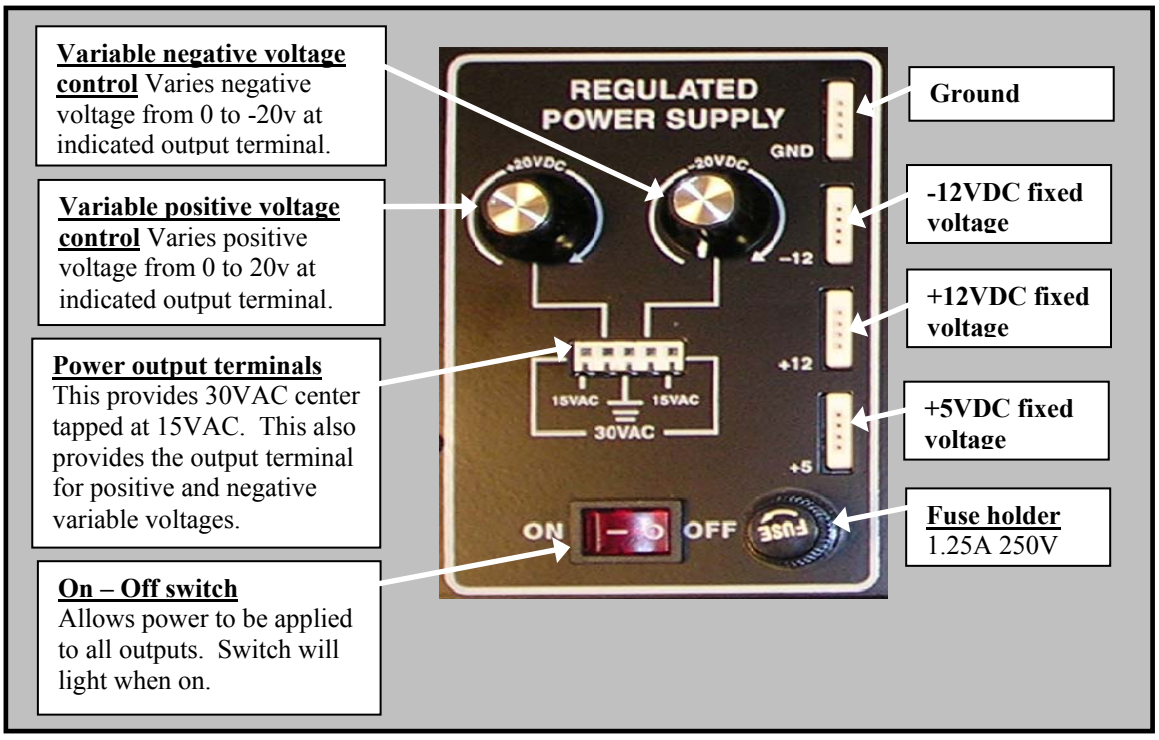

Variable negative voltage control Varies negative voltage from 0 to -20v at indicated output terminal.
Variable positive voltage control Varies positive voltage from 0 to 20v at indicated output terminal.
Power output terminals This provides 30VAC center tapped at 15VAC. This also provides the output terminal for positive and negative variable voltages.
On – Off switch Allows power to be applied to all outputs. Switch will light when on.
REGULATED POWER SUPPLY
+20VDC
-20VDC
GND
-12
+12
+5
15VAC
15VAC
30VAC
ON
OFF
FUSE
Ground
-12VDC fixed voltage
+12VDC fixed voltage
+5VDC fixed voltage
Fuse holder 1.25A 250V

Figure P-6

A variety of different voltages are available at the power output terminals. Because the Elenco trainer uses both the +20v and -20v adjustable voltage controls, a combined voltage of up to 40vdc is possible. (See Figure P-7)

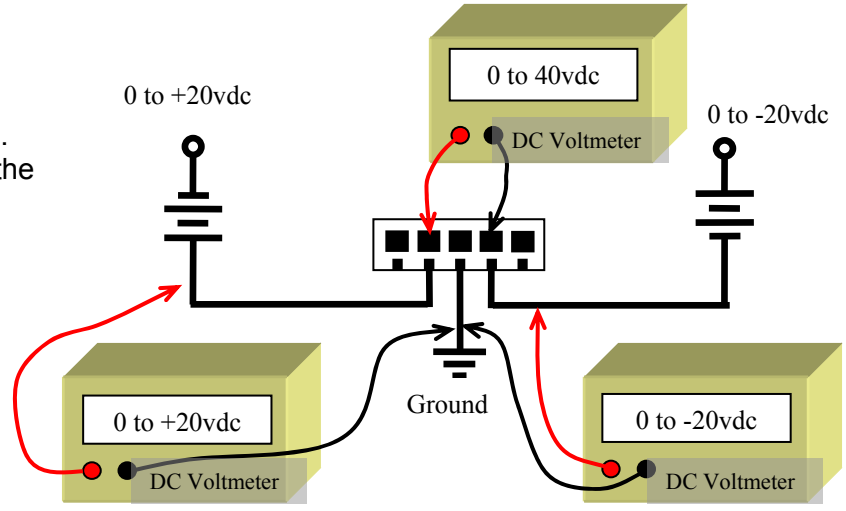


Figure P-7

The power supply section's output terminal block also allows for the stepped down AC voltage to be used direct from the center tapped transformer. The transformer provides a voltage of 30VAC from line to line or 15VAC from either line to the center tapped ground (See Figure P-8).

WARNING:
Do not short the 15 VAC output to ground!

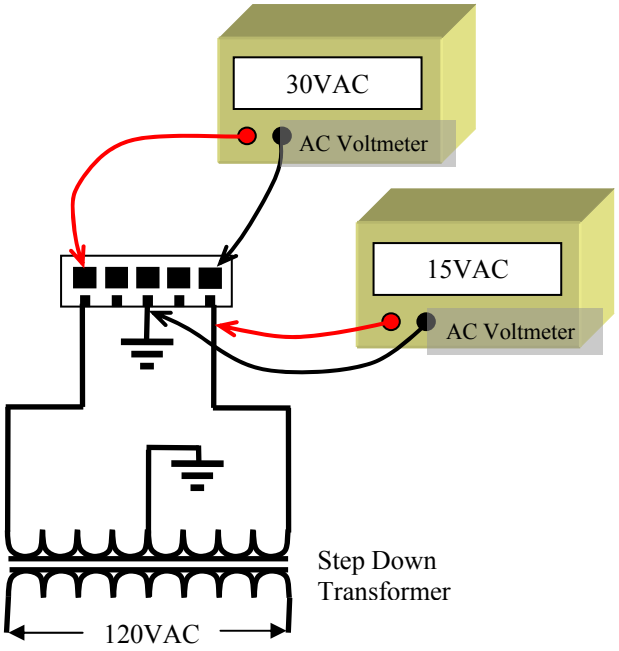


Figure P-8

Variable resistance section

The Elenco trainer has two built in variable resistors or "potentiometers" that are available to use for certain lab experiments. The values of the variable resistors are 1k ohm and 100k ohm max. Taking a resistance measurement from one side of the terminal block to the other will give the full value of the resistor (1k ohm or 100k ohm) regardless of the position of the knob. If you take a measurement from either end of the terminal block to the middle wiper connection, you will get a variable value that will change with respect to the position of the knob. (See Figure P-10)

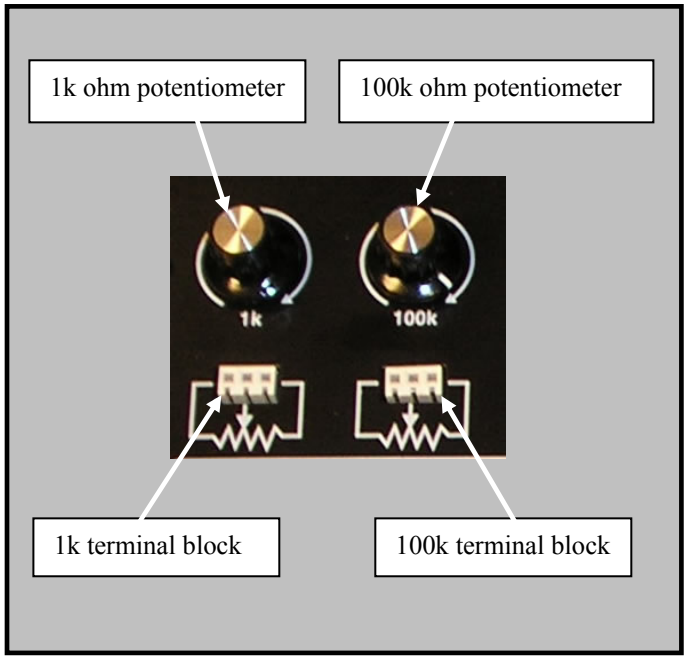


Figure P-9

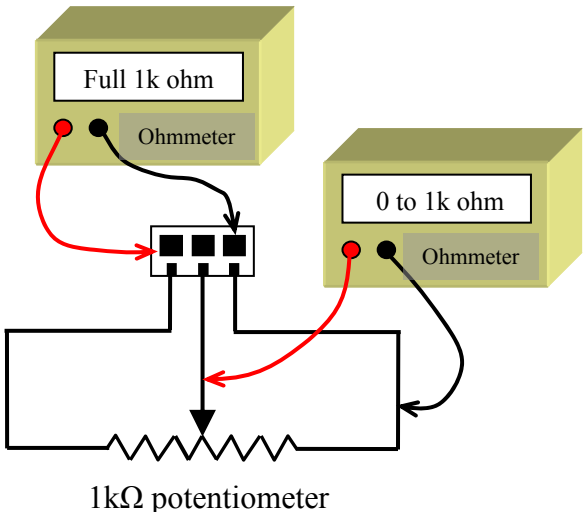


Figure P-10

Function / Signal Generator

The included function generator is capable of producing sine, square and triangle waveforms. The frequency of this generator is variable from one hertz to over 100,000 hertz in the following five ranges: 10-Hz, 100-Hz, 1-kHz, 10-kHz and 100-kHz. A fine adjustment control makes for easy selection of any frequency between these ranges. The output voltage amplitude is variable between 0 and 15-V_{P-P}. The output of the function generator may be taken from the terminal marked "FREQ" with respect to a ground terminal in the power supply section.

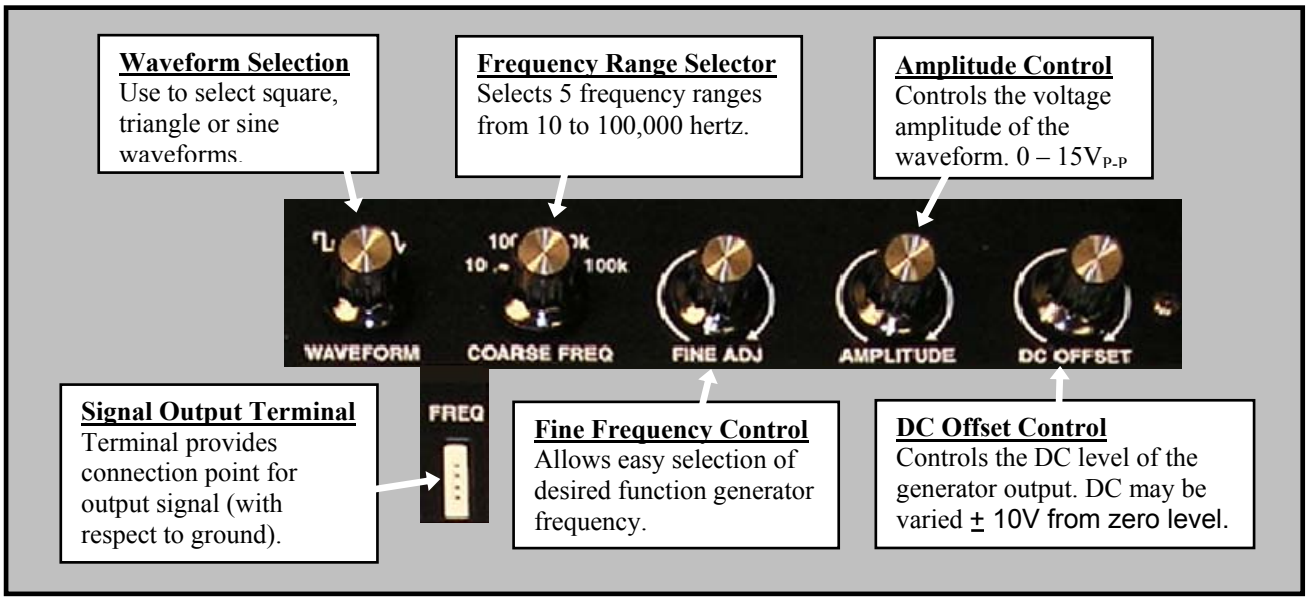

Waveform Selection
Use to select square, triangle or sine waveforms.
Frequency Range Selector
Selects 5 frequency ranges from 10 to 100,000 hertz.
Amplitude Control
Controls the voltage amplitude of the waveform. 0 – 15VP-P
WAVEFORM
COARSE FREQ
FINE ADJ
AMPLITUDE
DC OFFSET
100k
FREQ
Signal Output Terminal
Terminal provides connection point for output signal (with respect to ground).
Fine Frequency Control
Allows easy selection of desired function generator frequency.
DC Offset Control
Controls the DC level of the generator output. DC may be varied ± 10V from zero level.

Figure P-11

Digital Section

The digital section of the trainer consists of two "no bounce" logic switches, 8 LED indicator lamps, 8 data switches and a clock generator. The clock generator output is a 5V pulsating square wave. The frequency of the pulsations can be adjusted with the frequency range selector and fine frequency control in the function generator section.

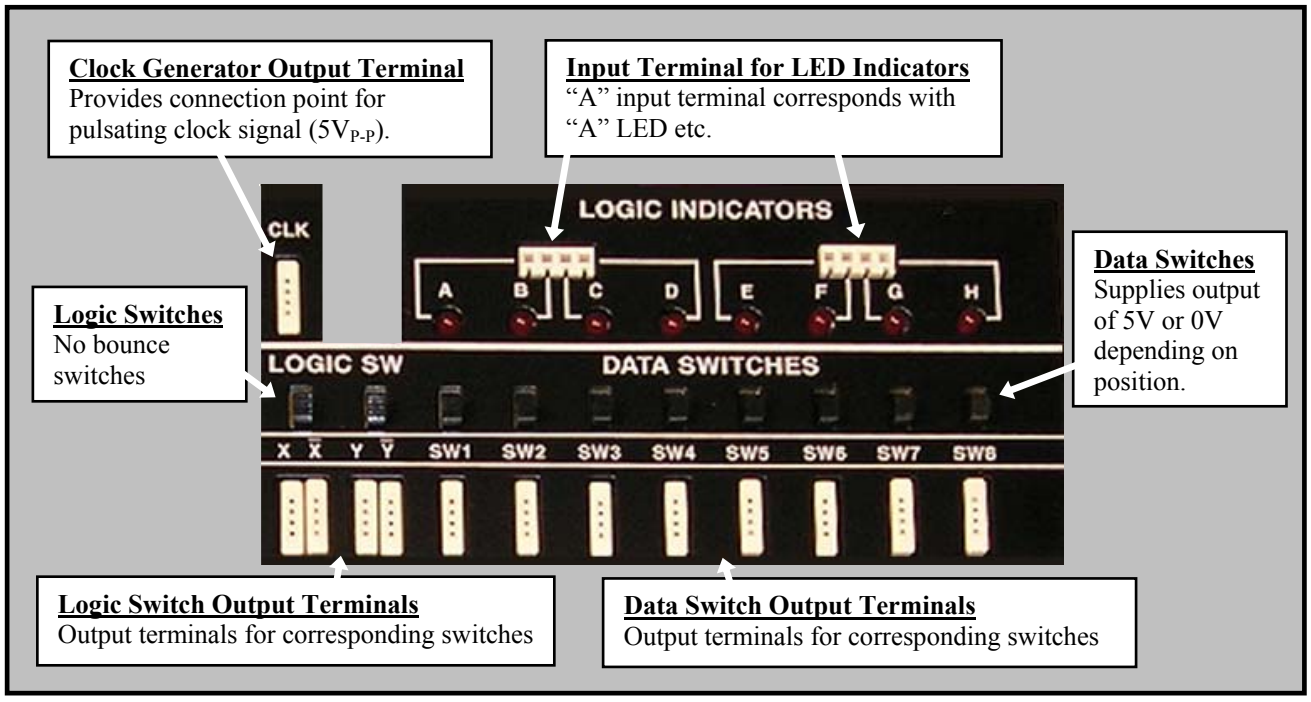

Clock Generator Output Terminal
Provides connection point for pulsating clock signal (5VP-P).
Input Terminal for LED Indicators
"A" input terminal corresponds with "A" LED etc.
CLK
LOGIC INDICATORS
A B C D E F G H
Logic Switches
No bounce switches
LOGIC SW
DATA SWITCHES
Data Switches
Supplies output of 5V or 0V depending on position.
X X Y Y SW1 SW2 SW3 SW4 SW5 SW6 SW7 SW8
Logic Switch Output Terminals
Output terminals for corresponding switches
Data Switch Output Terminals
Output terminals for corresponding switches

Figure P-12

Breadboard Section

The Elenco trainer is equipped with two breadboards containing a total of 1660 tie points including 6 independent bus lines.

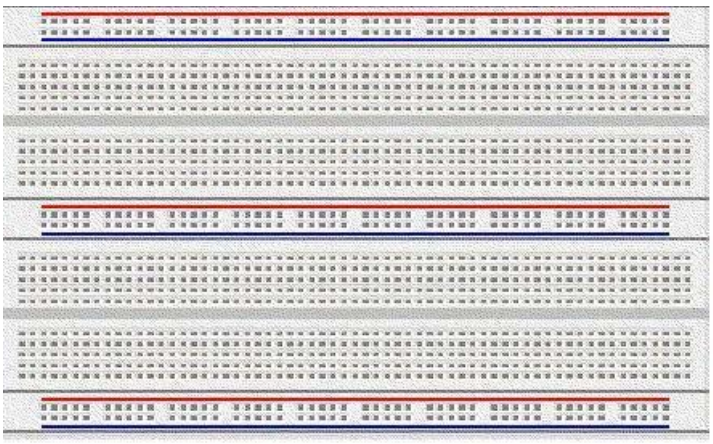


Figure P-13

The board is made of plastic with a matrix of holes. Wires and component leads can be pushed into the holes to make appropriate connections. Each "hole" on the board contains a metal spring contact. When a wire or component lead is pushed down into the hole an electrical connection is made with that hole's spring contact.

The breadboards provide an interconnection between certain holes on the board using metallic "bus" connections made underneath the surface. The holes are internally connected so that each 50 hole horizontal bus line is independent from the other and each small 5 hole vertical bus line is also connected independently. Figure P-14 shows the internal connections of the holes on the breadboard.

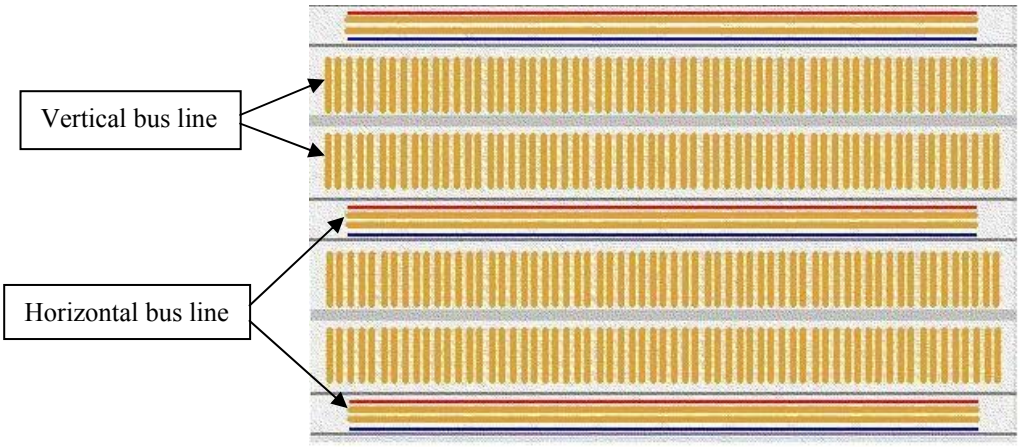


Figure P-14

Because of the built-in interconnections and the typical circuit board layout, some of the following techniques are commonly used when working with a breadboard.

- A jumper wire can be used to connect the positive source lead to one of the horizontal buss lines marked with a "plus" (+) sign.
- Another jumper wire can be used to connect the negative source lead or GND to one of the horizontal buss lines marked with a "minus" (-) symbol.
- A short jumper wire can then be used to connect each horizontal source connection row to the appropriate point(s) in the circuit on the vertical bus line portion of the board.
- When connecting component leads, plug one lead of a component into a vertical column hole and the other lead of the component into another vertical column hole in a separate bus line. Connect the component, spaced as necessary for the size of the component.

Figures P-15 & P-16 are sample series and parallel circuit connections using a breadboard. These are just a small sample of the many different methods and combinations for connecting circuits using breadboards. These examples are shown using the positive variable voltage supply.

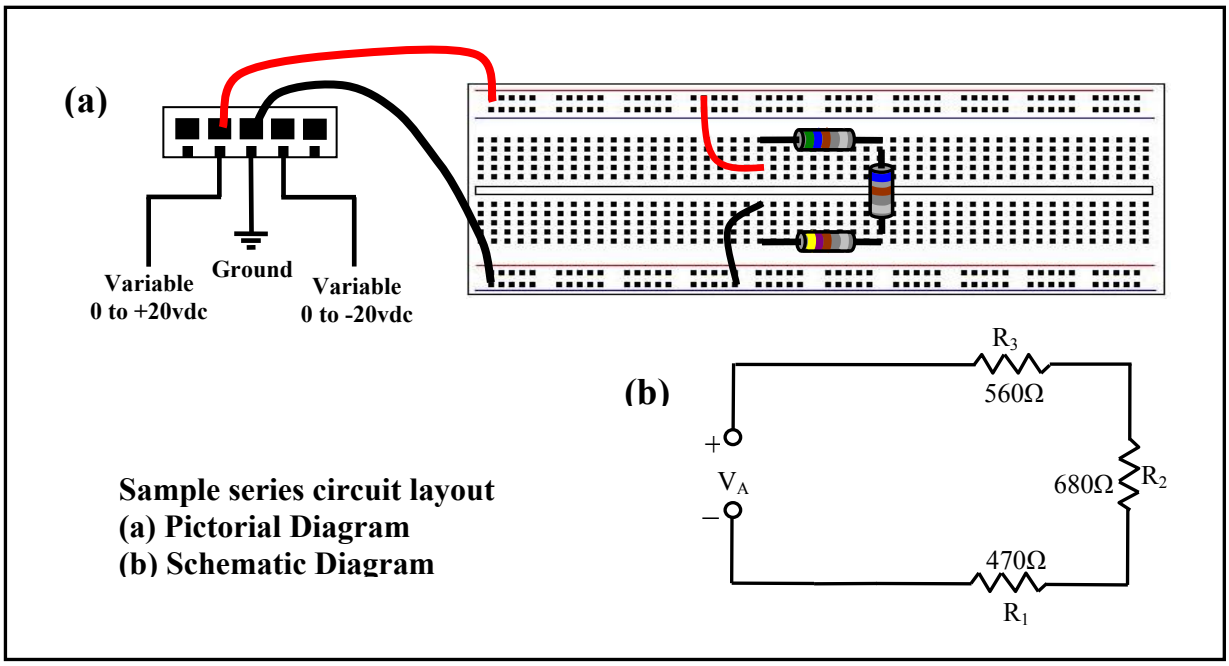


Figure P-15

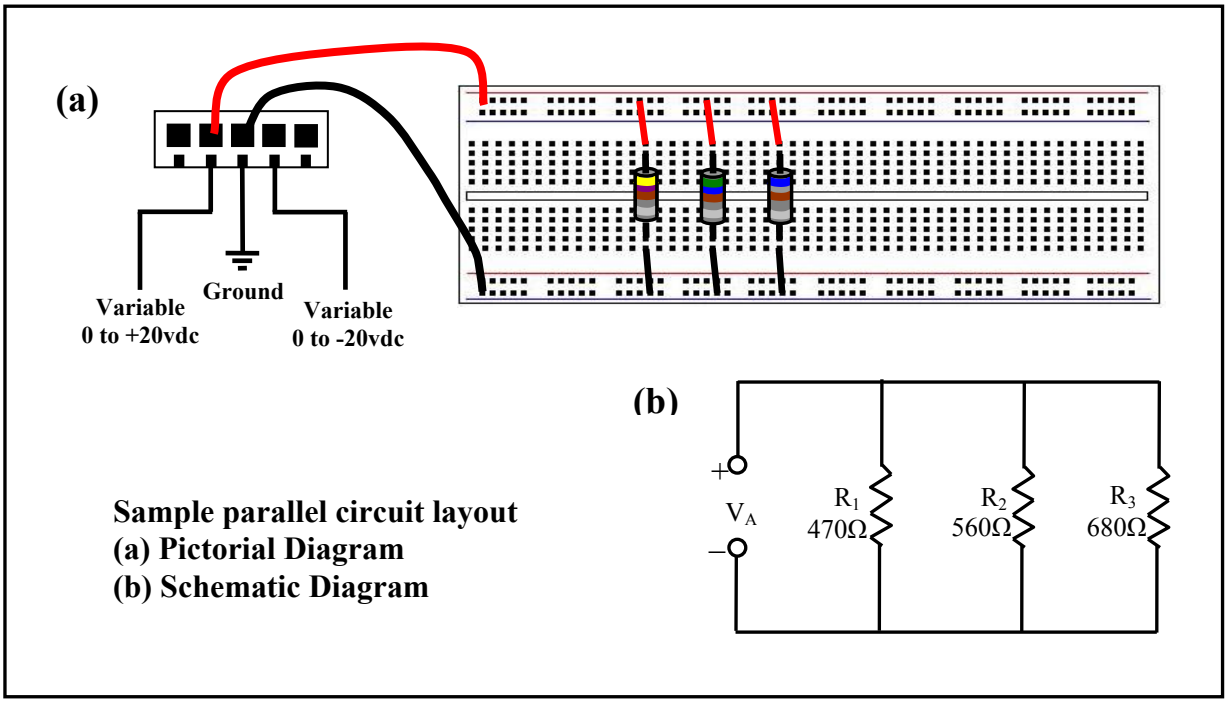


Figure P-16

Using Meters
Voltmeters

Project 1

Project Objectives:

- To learn how to safely and effectively measure DC voltage using a digital multi-meter.
- Gain practice in creating simple circuits from pictorial diagrams.
- Learn to adjust a variable DC source for a desired output voltage.

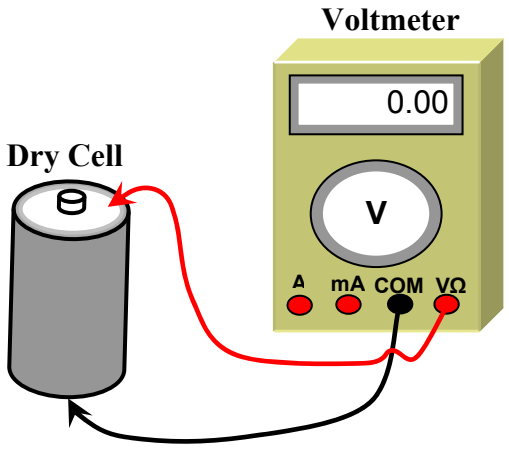
Items Needed:

Electronics Trainer	Digital multi-meter
Jumper Wires	1.5V dry cell battery

By completing this project you will learn some of the key procedures used to make safe and accurate measurements with a voltmeter. We will also introduce important points of meter care. Be sure to remember and use these key points whenever you use a meter.

1. Make sure the meter is set on the **correct function** (ac or dc volts, amperes, or ohms).
2. When using a non-autoranging meter, **make sure the range is set high enough** for what you are measuring. If you are not sure, start with the highest range and work down until the reading is the most accurate.
3. When measuring voltage, make sure the meter is **connected in parallel** with what you are measuring.
4. Be sure to **observe polarity** when measuring dc voltage.
5. Make sure to **remove power** when making changes to a circuit and connecting test leads.

Experiment 1



1. Following the safety guidelines listed above, use a digital multi-meter (DMM) and measure the voltage of a dry cell battery.

   Cell voltage measures _____ V.

2. What mode / function was the meter switched to make this measurement?

   (a) A_{DC} (b) V_{AC} (c) V_{DC} (d) Ω (e) A_{AC}

3. What voltage range will give the most accurate result for this measurement?

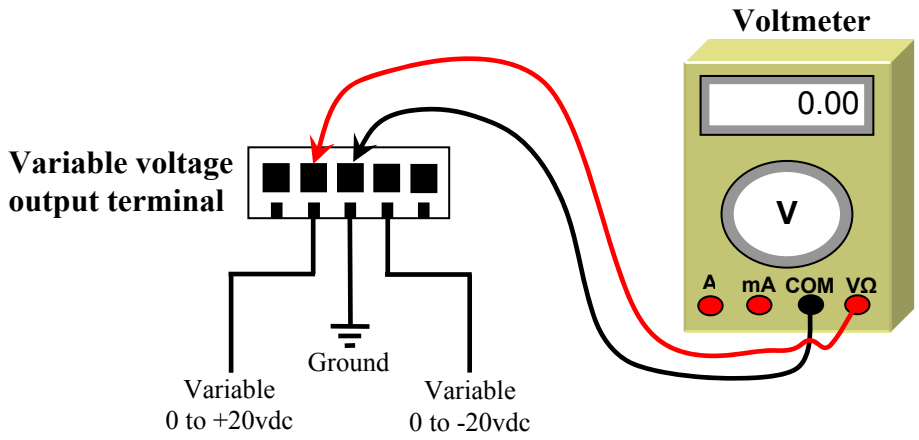
   (a) 200mV (b) 2V (c) 20V (d) 200V (e) 1000V

4. What cell terminal was the red lead connected to? (a) negative (b) positive

5. The negative terminal of the cell should be connected to the _____ test lead.

   (a) black (b) red

Experiment 2



1. Connect the voltmeter across the positive output of the variable voltage power supply on your Elenco electronics trainer. Carefully adjust the power supply to 5v, 15v, and 30v output settings, in that respective order. Have the instructor check your settings each time. (Hint) You will need to combine the positive and negative variable voltages on the Elenco trainer to reach 30v.

   5v setting correct. **Instructor initial:** _____

   15v setting correct. **Instructor initial:** _____

   30v setting correct. **Instructor initial:** _____

2. What mode / function was the meter switched to make this measurement?

   (a) A_{DC} (b) V_{AC} (c) V_{DC} (d) Ω (e) A_{AC}

3. What voltage range was the meter set to for the 5v and the 15v measurements?

   (a) 200mV (b) 2V (c) 20V (d) 200V (e) 1000V

4. What voltage range was the meter set to for the 30v measurement?

   (a) 200mV (b) 2V (c) 20V (d) 200V (e) 1000V

5. The red lead was connected to the _____ terminal of the power supply?

   (a) positive (b) negative

Using Meters
Ammeters

Project 2

Project Objectives:

- To learn how to safely and effectively measure DC current using a digital multi-meter.
- Gain practice in creating simple circuits from schematic and pictorial diagrams.
- Learn to adjust a variable DC source for a desired output current.

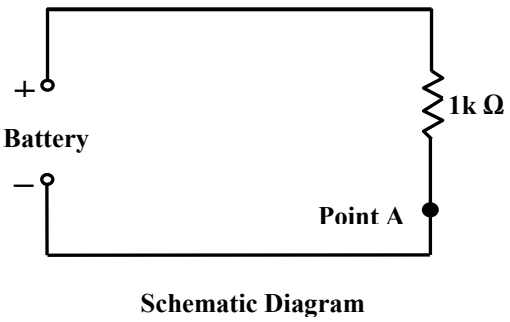
Items Needed:

- Electronics Trainer
- Digital multi-meter
- 1k Ω resistor
- Jumper Wires
- 1.5V dry cell battery

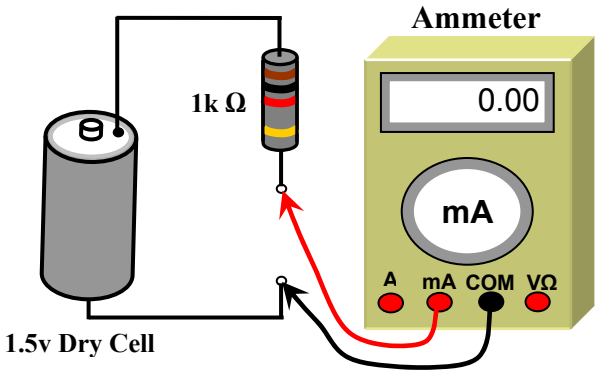
In this project please use the following safety precautions when connecting meters to make current measurements.

1. **Remove power from the circuit** prior to making changes and connecting meters.
2. Break the circuit in an appropriate place and **connect the meter in series.**
3. **Observe polarity** when measuring dc current.
4. **Use the correct meter mode / function** for what you are measuring (dc current mode).
5. Be sure to set **the range high enough for what you are measuring.** If unsure, start at the highest range and work down until an accurate reading is given.
6. After meter is connected properly, **turn power on and take reading.**

Experiment 1



Schematic Diagram



Pictorial Diagram

1. Set up the DMM to measure current from 0 to 2mA.

   What mode or function should the meter be set to?

   (a) A_{DC} (b) V_{AC} (c) V_{DC} (d) Ω (e) A_{AC}

2. Connect the circuit shown above. (The resistor color bands will be: brown, black, red, gold)

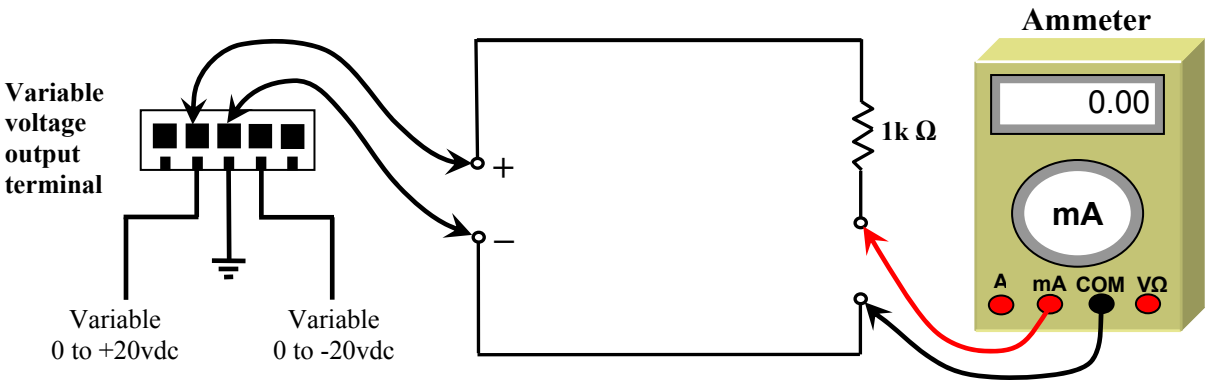
3. Break the circuit at point A and insert the meter. Make sure the meter is in series and there is a resistance in the circuit. If there is no resistance in the circuit a dead short will occur and the meter could get damaged or destroyed.

   Does your circuit look like the diagrams above? Check: (Yes _____, No _____)

4. Connect the 1.5V cell to the circuit and read the ammeter.

   Current measured is: _____ mA

Experiment 2



1. Disconnect the previous circuit. Set up the meter to read current in the range from 0 to 20mA.
2. With the power OFF, insert the 1kΩ resistor into the breadboard section of the Elenco trainer. Make sure the resistor leads are in separate bus lines so the circuit will not be "shorted".
3. Connect a jumper from the positive variable power supply terminal to one side of the resistor.
4. Connect another jumper from the middle "ground" terminal to the black test lead on the DMM.
5. Take the red test lead from the DMM and connect it to the open lead of the resistor. Your circuit should now look like the illustration above.
6. Set the voltage control on the power supply to the zero output setting. Turn the power on and slowly increase the output until you measure 10mA through the circuit. Have the instructor check your setting.

   Instructor initial: _____

7. What is the voltage applied to the circuit when the power supply is adjusted so that there is a current flow of 5mA?

   Please review the voltage safety rules!

   Voltage measures _____V. Current measures _____ mA.

Using Meters
Ohmmeters

Project 3

Project Objectives:

- To develop an understanding of the ohmmeter function of a DMM.
- To learn how to use the variable resistance section of the Elenco trainer.

Items Needed:

- Electronics Trainer	- Digital multi-meter	- 10k Ω resistor
- Jumper Wires	- 1k Ω resistor	- 47k Ω resistor

In this project please use the following safety precautions when connecting meters to make resistance measurements.

1. **Disconnect** the circuit from the power source.
2. **Isolate the component** being measured from the rest of the circuit.
3. **Use the correct meter mode / function** for what you are measuring. (ohms)
4. Be sure to **use the appropriate range** for the expected resistance.
5. When finished making measurements, be sure to **turn the meter OFF**.

Experiment 1

1. Using the resistance function of a DMM, measure and record the resistance value of a 1kΩ (1000Ω), 10kΩ (10,000Ω), and a 47KΩ (47,000Ω) resistor.

   The 1kΩ (brown, black, red) resistor measures _____ Ω.

   The 10kΩ (brown, black, orange) resistor measures _____ Ω.

   The 47kΩ (yellow, violet, orange) resistor measures _____ Ω.

2. Did the three resistors exactly measure to their specified value? _____

3. List some reasons why there may be differences from the measured and the specified value.

   _____

   _____

   _____

   _____

   _____

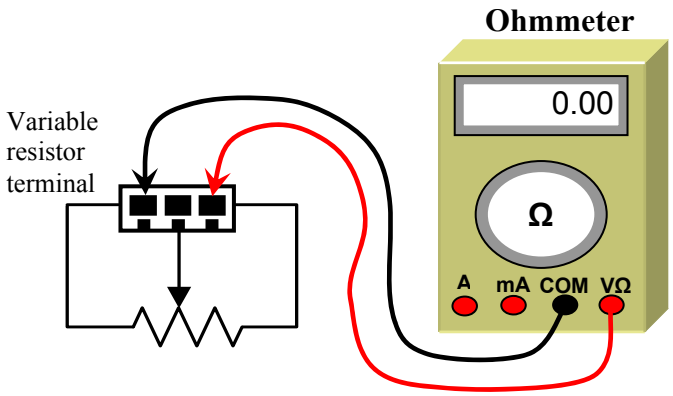
4. Which ohmmeter range should have been used to measure the three resistors?

   Range used for 1kΩ = _____

   Range used for 10kΩ = _____

   Range used for 47kΩ = _____

Experiment 2



1. Insert jumper wires into the two outside terminals for the 1kΩ and 100kΩ potentiometers (variable resistors) on your Elenco trainer. What are the resistance measurements? **Make sure the power supply is not connected!**

   1kΩ potentiometer measures: _____ Ω. Meter range used: _____

   100kΩ potentiometer measures: _____ Ω. Meter range used: _____

2. When the ohmmeter is connected in this manner, what happens when you attempt to adjust the resistance by turning the potentiometer's knob? _____

   Why? _____

   _____

   _____

3. Now move one of the jumper wires from the outside terminal to the middle "wiper" terminal. You should now be able to adjust the resistance by turning the potentiometer's knob.
4. Set the 1kΩ potentiometer to 350Ω. Have the instructor check your measurement.

   Meter range used: _____ **Instructor initial:** _____

5. Set the 100kΩ potentiometer to 18kΩ. Have the instructor check your measurement.

   Meter range used: _____ **Instructor initial:** _____

Ohm's Law

Relationship of I and V with a Constant R

Project 4

Project Objectives:

- To prove the direct relationship of current to voltage when a set resistance is given.
- To obtain more practice connecting circuits and using a DMM to make measurements.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- 10k Ω resistor (brown, black, orange)

While completing this project, keep in mind that Ohm's Law states (E = I x R)

- Be sure to **disconnect power** when connecting meters and making changes to the circuit!
- When measuring current, **make sure a resistance is always in the circuit** to avoid shorting the circuit and damaging the meter.

Experiment

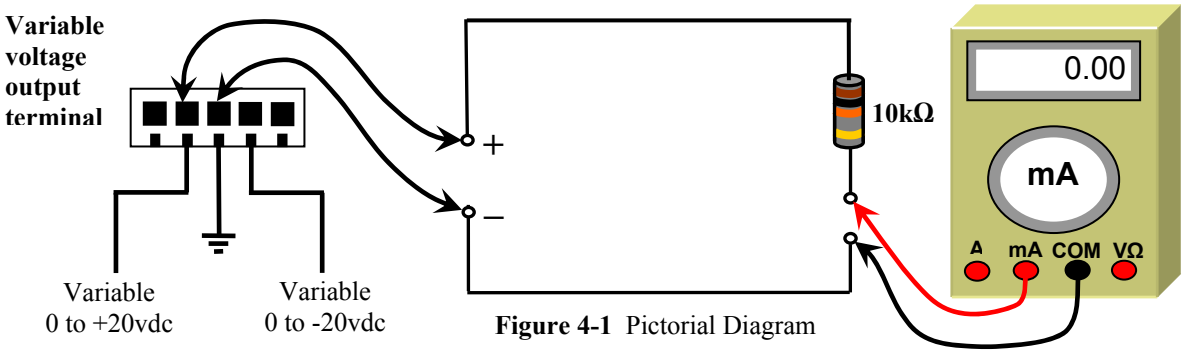


Figure 4-1 Pictorial Diagram

1. Select the correct meter function and range to measure **dc current** from 0 to 2mA.
2. Using the positive variable voltage as the source V, connect the circuit shown in figures 4-1 and 4-2. **Make sure the meter is in series with the circuit.**
3. Increase the positive variable voltage until the meter reads 1mA.
4. Making sure not to change the state of the variable voltage knob, turn off the power and disconnect the meter from the circuit.
5. Using Ohm's Law, calculate the expected voltage of this circuit.

   Calculated voltage = _____ V.

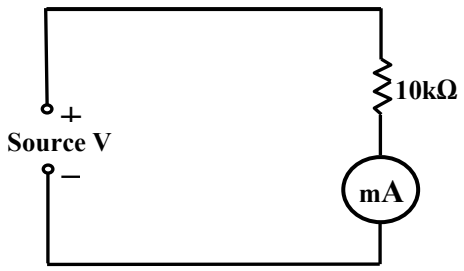


Figure 4-2 Schematic Diagram

6. Select the correct meter function and range to measure **dc voltage** from 0 to 20 volts.
7. Connect the circuit and the meter to take a voltage reading across the 10kΩ resistor. Remember, the meter must be in **parallel** when measuring voltage. See figure 4-3 for a schematic diagram. Make sure the variable voltage control knob has not been changed from when the current was set and apply power to the circuit.

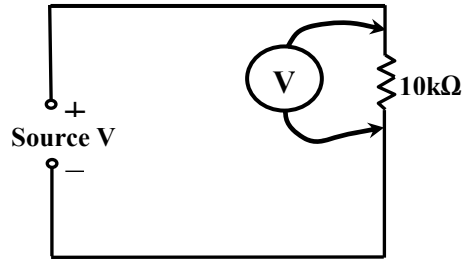


Figure 4-3

   Measured Voltage = _____ V.

Is the measured voltage close to the calculated value in step 5? _____

List some reasons why the measured voltage might not be perfectly accurate to the calculated value. _____

_____

_____

_____

8. Repeat steps 1 through 7, this time setting the current at 1.5mA. What is the calculated voltage
of this circuit?

   Calculated voltage = _____ V.

9. What is the measured voltage?

   Measured Voltage = _____ V.

10. Increasing the voltage of the circuit caused the current to _____.

    (a) increase (b) decrease

11. As this lab experiment clearly proved, electric current is _____ related to the voltage applied in the circuit.

    (a) directly (b) inversely

Ohm's Law

Relationship of I and R with a Constant V

Project 5

Project Objectives:

- To prove the inverse relationship of current to resistance when a set voltage is given.
- To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors 10kΩ, 3.3kΩ, 1kΩ

- Be sure to **disconnect power** when connecting meters and making component changes to the circuit!
- When measuring current, **make sure a resistance is always in the circuit** to avoid shorting the circuit and damaging the meter.

Experiment

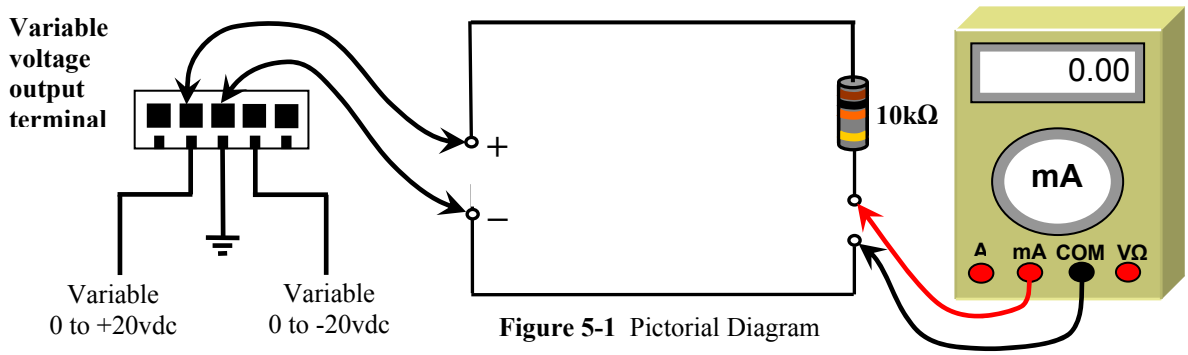


Figure 5-1 Pictorial Diagram

1. Select the correct meter range to measure **dc current** from 0 – 2mA.
2. Using the positive variable voltage as the source V, connect the circuit shown in figures 5-1 and 5-2. **Make sure the meter is in series with the circuit.**
3. Turn on the power supply and increase the positive variable voltage until the meter reads 1mA.
4. Measure the circuit voltage and be sure **not** to change it for the rest of the steps in this experiment.

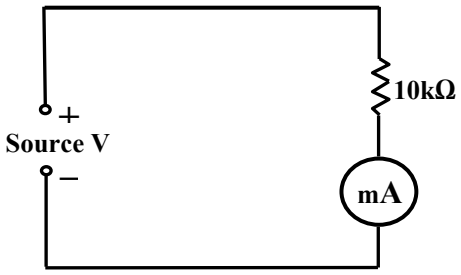


Figure 5-2 Schematic Diagram

Voltage measures = _____ V

5. Use Ohm's Law and calculate the resistance (R) from the measured values of voltage (V) and current (I).

Calculated Resistance = _____ Ω

6. What would the current of the circuit be if the 10kΩ resistor were replaced with a 3.3kΩ (orange, orange, red, gold) resistor?

New calculated current = _____ mA

7. What would the current of the circuit be if the 10kΩ resistor were replaced with a 1kΩ (brown, black, red, gold) resistor?

   New calculated current = _____ mA

8. Turn the power supply off and remove the 10kΩ resistor from the circuit. Replace it with a 3.3kΩ resistor.

9. Measure the new current reading. Make sure the meter range is set correctly to the calculation in step 6.

   Resistance now = 3.3kΩ Current now measures: _____ mA

10. Turn the power supply off and remove the 3.3kΩ resistor from the circuit. Replace it with a 1kΩ resistor.

11. Measure the new current reading. Make sure the meter range is set correctly to the calculation in step 7.

    Resistance now = 1kΩ Current now measures: _____ mA

12. Keeping the circuit voltage constant at _____ volts and decreasing the resistance caused the circuit current to _____.

    (a) increase (b) decrease

13. From this we conclude that current is _____ related to resistance.

    (a) directly (b) inversely

Ohm's Law

Relationship of Power to V with a Constant R

Project 6

Project Objectives:

- To show the use of the power formula by demonstrating how power is related to voltage squared for a set resistance.
- To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- 10k Ω resistor

- While completing this project, keep in mind that the power formula states that (P = E x I)
- Be sure to **disconnect power** when connecting meters and making component changes to the circuit!

Experiment

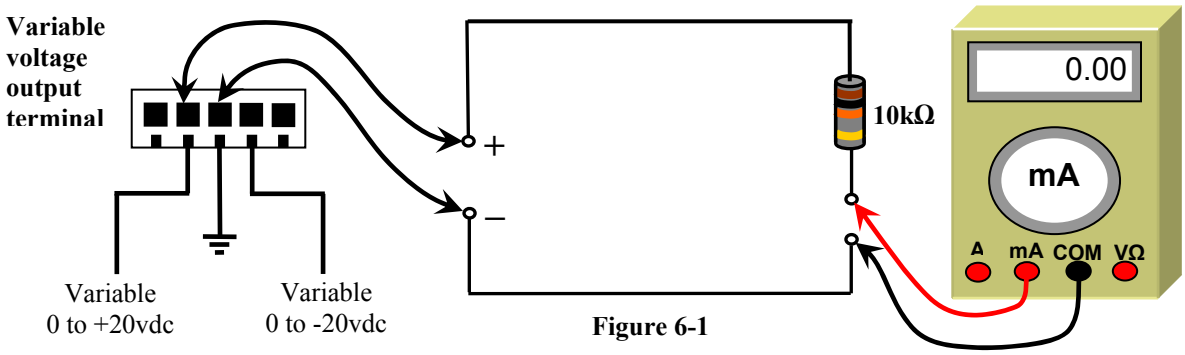


Figure 6-1

1. Connect the circuit shown in figures 6-1 and 6-2.
2. Adjust the Source V to obtain 1mA of current and measure the voltage.

   Current = _____ mA

   Voltage = _____ V

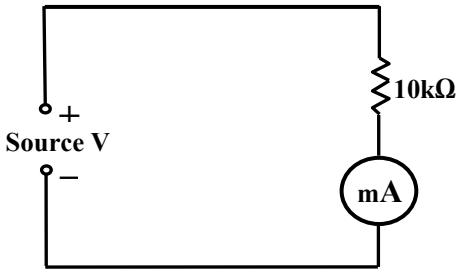


Figure 6-2

3. Using the power formula, calculate the power dissipated by the resistor.

   Calculated Power = _____ mW

4. Change the Source V to obtain 2mA of current and measure the voltage. Using the power formula, calculate the power dissipated by the resistor.

   Current now = _____ mA Voltage now = _____ V

   Calculated Power now = _____ mW

5. When we doubled the voltage the current increased by how many times? _____.

   Therefore the product of V x I increased _____ times.

6. Using the ($P = V^2/R$) formula, calculate the power for the measured values in step 4.

   V = _____ V R = _____ Ω

   P calculated = _____ mW

7. Change the Source V to 5 volts. Measure the current value and calculate the power by using both of the above formulas.

   V now = _____ V I now = _____ μA

   P calculated using the formula ($P = V \times I$) = _____ mW

   P calculated using the formula ($P = V^2/R$) = _____ mW

8. When compared to the 20 volt condition, we now have _____ the voltage.

   (a) *1/2* (b) *1/4* (c) *1/8* (d) *1/16*

9. When compared to the 20 volt condition, we now have _____ the power dissipation.

   (a) *1/4* (b) *1/8* (c) *1/16* (d) *1/32*

10. Assume this circuit has an applied voltage of 8 volts. Calculate and predict what the circuit current and power would be.

    Predicted current = _____ μA Predicted power = _____ mW

11. Change the circuit to 8 volts. Measure the current and calculate the power based on the measurements.

    Measured current = _____ μA Calculated power = _____ mW

12. Is the current with the applied 8 volts higher than when there were 5 volts applied? _____

    Is the calculated power higher or lower? _____

    Does the change correlate with the concept of power being equal to V^2/R? _____

Ohm's Law

Relationship of Power to I with a Constant R

Project 7

Project Objectives:

- To show the use of the power formula by demonstrating how power is related to current squared for a set resistance.
- To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- 10k Ω resistor

- While completing this project, keep in mind that the power formula states that (P = E x I)
- Be sure to **disconnect power** when connecting meters and making component changes to the circuit!

Experiment

1. Connect the circuit shown in figure 7-1.
2. Adjust the applied voltage (V_A) to 14 volts.
3. Break the circuit and insert an ammeter to measure the current.

   I = _____ mA

4. Use the measured values of *V* and *I* and calculate *P* using the power formula.

   P calculated = _____ mW

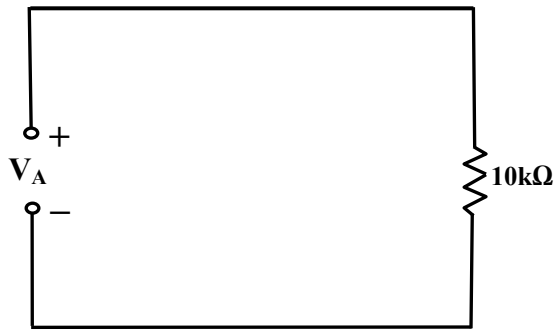


Figure 7-1

5. Decrease V_A until I equals 1/2 its original value. Measure the new voltage and calculate *P* using both formulas.

   V now = _____ V I now = _____μA

   P calculated using the formula (*P = V x I*) _____ mW

   P calculated using the formula (I^2 *x R*) _____ mW

   P calculated is _____ the power dissipated when *I* was double the value of current.

   (a) *1/2* (b) *1/4* (c) *1/8* (d) *1/16*

6. We can conclude from this that power is proportional to I^2 when the resistance remains unchanged. So if the current in a circuit doubles, the power dissipation will increase by

   _____ times. (a) *1* (b) *2* (c) *3* (d) *4*

7. If the current in a circuit decreases to one-third its value, the power must decrease to

   _____ its value. (a) *1/3* (b) *1/4* (c) *1/6* (d) *1/9*

8. What would happen if V_A was changed to 4.67 volts (approximately 1/3 the original 14V value)

   New V_A = _____ V *V* x *I* now = _____ mW

   I_{CALC} = _____ μA I^2 x *R* now = _____ mW

   Is the power approximately one-ninth that when 14 volts were applied? _____

Resistors
Resistor Color Codes

Project 8

Project Objective:

- To provide a hands-on experience with the resistor color code.
- To determine if the resistor is operating within its specified tolerance by using an ohmmeter to measure its resistance.

Items Needed:

- Digital multi-meter
- Resistors: **2 watt** - 270kΩ
  1 watt - 6.2kΩ
  1/2 watt - 11Ω, 2kΩ, 2.2kΩ, 300kΩ, 750kΩ, 10MΩ
  1/4 watt - 150Ω, 5.6kΩ
  1/8 watt - 1.2kΩ, 39kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. List the 10 colors used in the resistor color code to represent the following numbers.

   0 = _____ 5 = _____

   1 = _____ 6 = _____

   2 = _____ 7 = _____

   3 = _____ 8 = _____

   4 = _____ 9 = _____

2. List the colors used in the resistor color code to represent the following tolerance levels.

   The color used to represent 5% tolerance = _____

   The color used to represent 10% tolerance = _____

   How is a 20% tolerance represented? _____

3. Complete the table on the next page to determine if the resistors are operating within their specified tolerance ratings.

   Example:
   If we have a 1kΩ resistor with a 5% tolerance that measures 965Ω we can find if it is operating within its tolerance rating by dividing the smaller number by the larger number and subtracting from 100%. In this case the smaller number is the measured value and the larger number is the given (color code) value.

   If we take 965Ω and divide by 1000Ω we get .965

   We end up with a percentage of the measured value to the given value. To find out if the resistor is operating within its tolerance we need to subtract from 100% so we move the decimal point two places.

   100% – 96.5% = 3.5%

The percent of difference between the measured value and the given color code value of the resistor is 3.5%. Therefore the 1kΩ resistor is operating within its 5% tolerance.

Complete the table below. Use an ohmmeter to measure each resistor. Refer to the example above to calculate if each resistor is operating within its tolerance rating.

	Resistor measures?	% of difference	In tolerance (yes/no)
270kΩ - 2 watt			
6.2kΩ - 1 watt			
11Ω - 1/2 watt			
2kΩ - 1/2 watt			
2.2kΩ - 1/2 watt			
300kΩ - 1/2 watt			
750kΩ - 1/2 watt			
10MΩ - 1/2 watt			
150Ω - 1/4 watt			
5.6kΩ - 1/4 watt			
1.2kΩ - 1/8 watt			
39kΩ - 1/8 watt			

4. Use Ohm's Law to determine if the resistor's power rating would be sufficient in each of the following conditions.

   Would the power rating be sufficient if 11 volts were applied across the 1.2kΩ resistor?

   _____

   Would the power rating be sufficient if 50 mA were flowing through the 150Ω resistor?

   _____

   Would the power rating be sufficient if 350 volts were applied across the 300kΩ resistor?

   _____

Series Circuits

Resistance in Series Circuits

Project 9

Project Objective:

- To verify the series circuit resistance formula by making resistance measurements under various circuit conditions.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 3-10kΩ, 47kΩ, 100kΩ, & 220kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. Connect the circuit as shown in Figure 9-1.

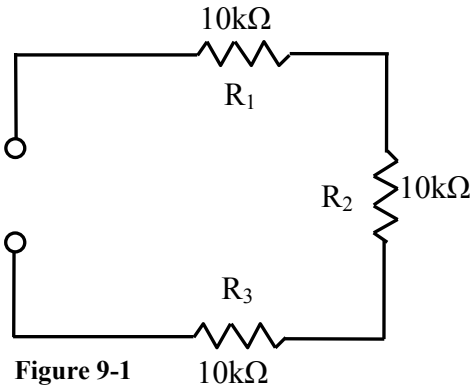


Figure 9-1

Remember! Disconnect the power supply in this project!

2. Measure the resistance of the entire circuit using an ohmmeter. Remember to correctly label your answers.

   R total = _____.

3. Measure the resistance of each individual resistor, and record the values below.

   R_1 = _____.

   R_2 = _____.

   R_3 = _____.

4. Since the total resistance of a series circuit equals the sum of the individual resistances,

   $R_1 + R_2 + R_3$ = _____.

   Therefore R_T = _____.

5. What would the new R_T be if R_3 were changed to a 47kΩ resistor?

   Predicted R_T = _____.

6. Change R_3 to 47kΩ and measure the new total resistance.

   New R_T = _____.

7. In conclusion, if any single resistance in a series circuit increases, then the total resistance will _____. If any single resistance in a series circuit decreases then the total resistance will _____.

8. Configure the circuit so that R_1 = 220kΩ, R_2 = 100kΩ, and R_3 = 47kΩ. Predict R_T and then measure R_T to verify.

   Predicted R_T = _____ Measured R_T = _____

   Does the measured value equal the predicted value? _____

   What could cause a difference? _____

Series Circuits

Current Flow in Series Circuits

Project 10

Project Objective:

- To verify that the current in a series circuit is the same no-matter where the measurement is taken in the circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 4.7kΩ, 3.3kΩ, & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 10-1.

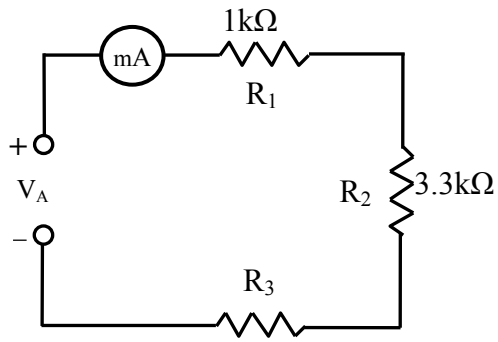


Figure 10-1

2. Apply 11 volts to the circuit and measure the current.

   Current = _____.

3. Swap positions of R_1 and the ammeter and record the new current reading.

   Current reading is now _____.

4. Swap positions of the ammeter with each of the remaining resistors and record the current readings.

   In every case, the current reading was _____.

   It doesn't matter where the current measurement is taken in a series circuit. The current reading remains the same. This indicates that there is only _____ path for current to flow.

5. Change R_3 to a 10kΩ resistor. Move the meter to different points in the circuit and record the current readings.

   In all cases, the current reading was _____.

   By increasing the resistance in a series circuit we are affecting the current flow through all parts of the circuit. If we were to change R_T by decreasing it, would it change the I_T? _____

   Would I_T increase or decrease? _____

6. Now change V_A to 30 volts. Move the meter to different points in the circuit and record the current readings.

   In all cases, the current reading was _____.

   Increasing the V_A in a series circuit caused I_T to change through all parts of the circuit. It changed by the same amount in every point in the circuit. This is because the current throughout the entire series circuit is _____ current.

   a.) different b.) alternating c.) the same d.) direct

Series Circuits

Voltage in Series Circuits

Project 11

Project Objective:

- To use measurements and calculations to demonstrate the proportional relationship of resistance and voltage in a series circuit.

Items Needed:

- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 4.7kΩ, 18kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 11-1.

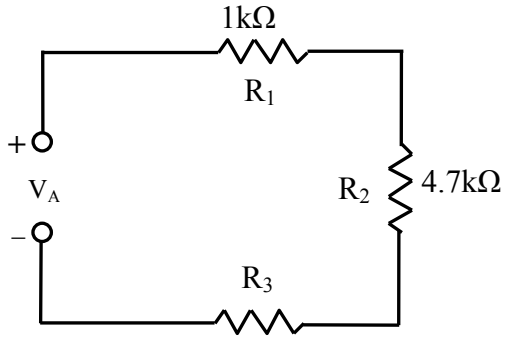


Figure 11-1

2. Apply 12.5 volts to the circuit and fill in the following table.

V_A =	
V_1 =	
V_2 =	
V_3 =	
I_T =	

3. Since the current is the same through all the resistors, the voltage drop across each resistor is directly related to its _____.

4. Add the individual voltage drops and record the sum.

   $V_1 + V_2 + V_3$ = _____.

   Kirchhoff's Voltage Law states that the sum of voltage drops around a closed loop circuit must equal the applied voltage (V_A). Does it? _____.

5. Calculate the percentage of the applied voltage that is dropped by each of the resistors. Use the following example for V_1 then solve for V_2 & V_3. **Percentage** = $\frac{V_1}{V_A}$ **x 100**

   V_1 = _____ % of V_A

   V_2 = _____ % of V_A V_3 = _____ % of V_A

6. Predict what value V_3 would be if V_A were increased to 22 volts.

   V_3 Predicted = _____.

   Change V_A to 22 volts and measure V_3.

   V_3 Measured = _____.

7. V_3 is now what percentage of V_A? _____ %

   Is this the same percentage as when the applied voltage = 12.5 volts? _____

Changing the applied voltage does not change the voltage drop percentages of V_A. If one of the *R*s were changed, would the distribution percentages change? _____

In conclusion, in a series circuit, the largest *R* will drop the _____ voltage, and the smallest *R* will drop the _____ voltage.

8. Assuming V_T = 22 volts, calculate V_1 and V_2 using the voltage divider formula.

$$\left(V_x = \frac{R_x}{R_T} \times V_T\right)$$

V_1 calculated = _____. V_2 calculated = _____.

9. Measure V_1 and V_2 with 22 V applied to the circuit.

V_1 measured = _____. V_2 measured = _____.

Do the measured values of V_1 and V_2 validate the calculations using the voltage-divider formula? _____

Series Circuits

Power in a Series Circuit

Project 12

Project Objective:

- To demonstrate that power distribution in a series circuit is directly related to the distribution of resistance.
- To verify that the total power equals the sum of all the individual power dissipations.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 4.7kΩ & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 12-1.

2. Apply 20 volts (V_A) to the circuit. Measure each of the individual voltage drops and the current, and then calculate the power dissipated by each resistor.

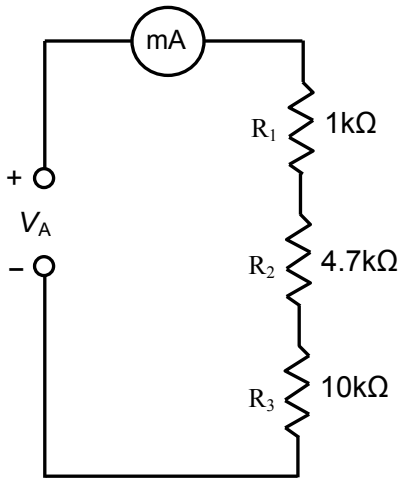


Figure 12-1

V_1 = _____

V_2 = _____

V_3 = _____

I_T = _____

P_1 calculated = _____

P_2 calculated = _____

P_3 calculated = _____

Since the current is the same through all the resistors, the power dissipated by each resistor is directly related to its _____.

a.) power rating b.) physical size c.) composition d.) resistance

The resistor with the largest value *R* will dissipate the _____ power.

a.) most b.) least

The resistor with the smallest value *R* will dissipate the _____ power.

a.) most b.) least

3. Record the sum of all the individual resistor power dissipations.

$P_1 + P_2 + P_3$ = _____.

Calculate the total power by using the formula: $P_T = V_T \times I_T$

$P_T = V_T \times I_T$ = _____.

In conclusion, the total power in a series circuit equals the _____ of all the individual power dissipations.

a.) product b.) sum

4. What is the percentage of P_1 to P_3? P_1 = _____ % of P_3.

   The percentage of power between two resistors in a series circuit is the same as the percentage of _____ between the same two resistors.

5. What would happen to P_T if the applied voltage were reduced to half its original value? (Fill in the appropriate blanks using fractions.)

   P_T = _____ as much as it did before. The individual power dissipations would be equal to _____ the original value.

   When the voltage is decreased to one-half for a given resistance, the circuit current will _____ to _____. This causes the power, or V x I to be _____ the original value. If the resistances remain the same but the voltage is changed, the actual value of power dissipated will (*change, not change*) _____ but the percentage of P_T dissipated by a given resistance will (*change, not change*) _____.

6. Change the V_A to 10 volts. Fill in the blanks by calculating and measuring the following values.

   V_A = _____. V_2 = _____.

   I = _____. P_2 = _____.

   P_T = _____. V_3 = _____.

   V_1 = _____. P_3 = _____.

   P_1 = _____.

   When the applied voltage was decreased to half its original value, current decreased to _____ its original value and the total power dissipated in the circuit decreased to _____ its original value. The power dissipated by each resistor also decreased to _____ its original value.

   Does this information verify step 5? _____

Series Circuits

Detecting an Open in a Series Circuit

Project 13

Project Objective:

- To provide experience with the change that occurs when an open develops in a series circuit.
- To prove that the applied voltage appears across the open portion of a series circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 4.7kΩ & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 13-1.

2. Adjust the V_A to 15 volts. Measure and record the current and individual voltage drops.

   I_T = _____

   V_1 = _____

   V_2 = _____

   V_3 = _____

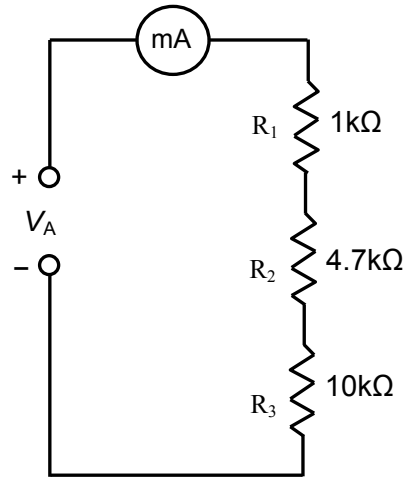


Figure 13-1

3. Simulate an open circuit by removing R_2 and leave the circuit open between R_1 and R_3. Measure and record the current and individual voltage drops.

   I_T = _____

   V_1 = _____

   V_2 *(across open)* = _____

   V_3 = _____

   Since there is only one path for current to flow in a series circuit, creating an open within the series circuit will cause _____.

   a.) continuity b.) discontinuity

   The total resistance of the circuit then appears to be infinitely _____.

   a.) high b.) low

   The voltage drop across R_1 and R_3 were _____ volts because, with zero current, the I x R must equal _____.

   If any part of a series circuit opens, R_T will (*increase, decrease*) _____ to _____ and I_T will (*increase, decrease*) _____

to _____. The voltage drops across the unopened resistors will (*increase, decrease*) _____ to _____ and the voltage across the open resistor will (*increase, decrease*) _____ to _____.

4. Predict the results if R_3 were to be removed from the circuit instead of R_2.

   I_T = _____

   V_1 = _____

   V_2 = _____

   V_3 = _____

5. Replace R_2 and remove R_3 as suggested in step 4. Make the following measurements and record the results below.

   I_T = _____

   V_1 = _____

   V_2 = _____

   V_3 *(across open)* = _____

   Do these results verify the results of step 3? _____

Series Circuits

Detecting a Short in a Series Circuit

Project 14

Project Objective:

To provide experience with the changes that occur when a short develops in a series circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 47kΩ & 2 - 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 14-1.
2. Adjust the V_A to 15 volts. Measure and record the current and individual voltage drops.

   I_T = _____

   V_1 = _____

   V_2 = _____

   V_3 = _____

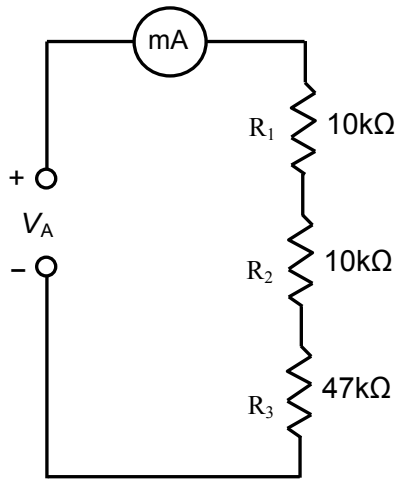


Figure 14-1

3. Simulate a resistor "shorting out" by removing R_3 and replacing it with a jumper wire. Measure and record the circuit current and individual voltage drops.

   I_T = _____

   V_1 = _____

   V_2 = _____

   V_3 *(across short)* = _____

   Shorting out R_3 caused the circuit R_T to (*increase, decrease*) _____ to _____ ohms. This caused I_T to (*increase, decrease*) _____. The new current value caused the voltage drops across the unshorted resistors in the circuit to (*increase, decrease*) _____. The resistance of the simulated short (jumper wire) is essentially _____ ohms. Therefore, since $V = I \times R$, the voltage drop across the shorted resistor of a series circuit will essentially equal _____. We can conclude that if there is a short in any part of a series circuit, the R_T will (*increase, decrease*) _____; I_T will (*increase, decrease*) _____; the voltage drop across the unshorted R will (*increase, decrease*) _____; and the voltage across the shorted R will (*increase, decrease*) _____; to _____.

Parallel Circuits

Resistance in Parallel Circuits

Project 15

Project Objective:

- To verify that the total resistance in a parallel circuit is less than the least value resistance in parallel.
- To provide practice using parallel resistance formulas and confirming them through circuit measurements.

Items Needed:

- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 18kΩ, 100kΩ, 220kΩ & 3 - 10kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. Connect the circuit as shown in Figure 15-1.

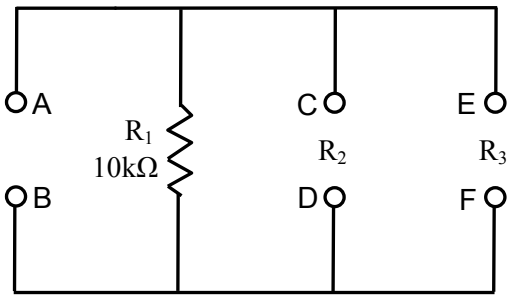


Figure 15-1

2. Measure R_T at points A and B.

   R_T = _____.

3. Calculate R_T if a 10kΩ resistor were to be inserted between points C and D. Use the product over sum formula.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

   R_T calculated = _____.

   When two equal resistors are connected in parallel,

   the total resistance is equal to _____ the resistance of one branch.

4. After calculating R_T, use an ohmmeter and measure at points A and B with a second 10kΩ resistor inserted at points C and D.

   R_T measured = _____.

5. Calculate R_T if a third 10kΩ resistor were to be inserted between points E and F. Use the reciprocal formula.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

   R_T calculated = _____.

   When three equal resistors are connected in parallel, the total resistance of the circuit is equal

   to _____ the resistance of one branch.

6. After calculating R_T, use the ohmmeter and measure at points A and B with a third 10kΩ resistor inserted at points E and F.

   R_T measured = _____.

7. Using both parallel resistance formulas calculate R_T if R_2 were changed to 100kΩ and R_3 were changed to 18kΩ.

   Product over sum, R_T Calculated = _____.

   Reciprocal, R_T Calculated = _____.

8. Change the circuit as described in step 7 and measure the total resistance of the circuit at points A and B.

   R_T measured = _____.

   In conclusion, the total resistance in a parallel circuit is less than the (*highest, lowest*)

   _____ value resistive branch in parallel.

9. Now replace R_3 with a 220kΩ resistor. Calculate the total resistance using either formula then measure R_T at points A and B.

   R_T calculated = _____.

   R_T measured = _____.

   Does this result confirm the conclusion in step 8? _____

   No matter how large the value of resistive branch that is added to a parallel circuit, the total resistance of the parallel circuit will be (*higher, lower*) _____ than the least value resistive branch in parallel.

Parallel Circuits

Current Flow in Parallel Circuits

Project 16

Project Objective:

- To verify that the amount of current through parallel branches is inverse to the branch's resistance value.
- To confirm Kirchhoff's Current Law by verifying that the total current in a parallel circuit equals the sum of the individual branch currents.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 10kΩ, 18kΩ, 47kΩ, 100kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 16-1 and set the applied voltage to 10 volts.

2. Find the total circuit current and the current flowing through each parallel branch by breaking the circuit at the appropriate "X" in Figure 16-1 and measuring with an ammeter.

   Remember, the ammeter leads must be connected in series when taking current measurements!

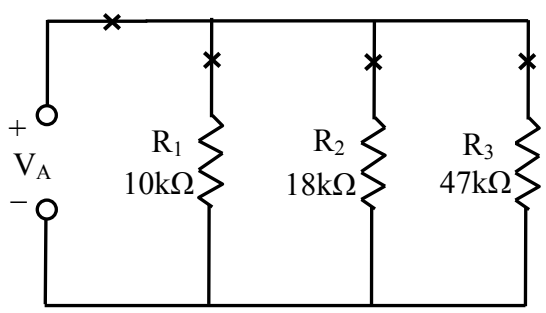


Figure 16-1

I_1 = _____. I_3 = _____.

I_2 = _____. I_T = _____.

The resistance value in R_2 is roughly _____ times larger than the resistance in R_1. The current through R_2 is roughly _____ the current through R_1. The resistance value in R_3 is roughly _____ times larger than the resistance in R_1. The current through R_3 is roughly _____ the current through R_1. We can conclude from this experiment that the current through parallel branches is inversely proportional to the branches' _____ . We can also observe from the measured currents that the total circuit current is equal to the _____ of the individual branch currents.

3. Remove R_2 from the circuit and replace it with a 100kΩ resistor. Leave the applied voltage at 10 volts and measure and record the circuit currents one at a time.

   I_1 = _____. I_3 = _____.

   I_2 = _____. I_T = _____.

   Did the current through R_1 or R_3 change when R_2 was increased to 100kΩ? _____

Did the total current change? _____ If so, was the change in I_T the same as the change in I_2? _____ This proves that I_T is the sum of all the _____ currents. Since R_1 is 1/10 the value of R_2, I_1 should be _____ times the value of I_2. Is it? _____

Parallel Circuits

Voltage in Parallel Circuits

Project 17

Project Objective:

- To verify that branch voltages are equal in a parallel circuit.
- To verify that each branch voltage equals the applied voltage in parallel circuits.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 3 - 10kΩ, 100kΩ, 220kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 17-1.

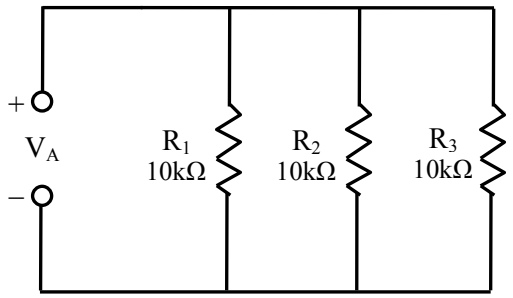


Figure 17-1

2. Apply 12 volts to the circuit and measure and record all of the branch voltages.

   V_A = _____.

   V_1 = _____.

   V_2 = _____.

   V_3 = _____.

   What two facts can we conclude from the above measurements? _____

   _____

   _____

   _____

   _____

3. Change the value of R_3 from 10kΩ to 100kΩ. Keep the applied voltage at 12 volts and measure all of the branch voltages and the source voltage and record the results below.

   V_A = _____. V_2 = _____.

   V_1 = _____. V_3 = _____.

   Did all of the voltages measure the same as in step 2? _____

   This indicates that if the resistance value of a branch in a parallel circuit is changed, it will not affect the branch voltages. These branch "voltages" are not separate voltages but are in fact the same voltage.

   Does the total circuit current change if one branch resistance changes? _____

   Does the current change through the unchanged resistance branches? _____

   Does the current change through the changed resistance branch?_____

4. Add a fourth parallel branch by inserting a 220kΩ resistor to the end of the circuit. We will label this resistor as R_4. Measure and record the circuit voltages with the 12 volts applied.

   V_A = _____. V_3 = _____.

   V_1 = _____. V_4 = _____.

   V_2 = _____.

   We can conclude that when we add additional resistive branches to a parallel circuit, this change _____ affect the voltage across the other parallel branches.

Parallel Circuits

Power in a Parallel Circuit

Project 18

Project Objective:

- To verify that the power dissipation in a parallel branch is inverse to that branch's resistance value.
- To verify that total power in a parallel circuit is equal to the sum of all the individual branch power dissipations.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 2 - 10kΩ, 18kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 18-1.

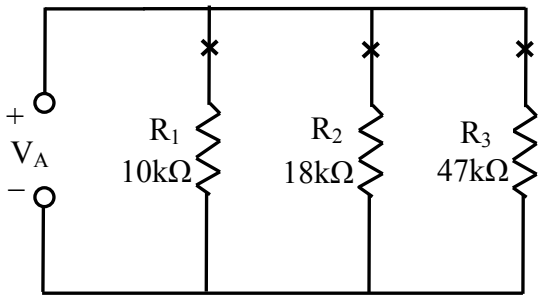


Figure 18-1

2. Apply 12 volts to the circuit. Break the circuit at the appropriate "X" in Figure 18-1 to measure each of the branch currents. Record the results below.

   I_1 = _____.

   I_2 = _____.

   I_3 = _____.

   Since the total circuit current is equal to the _____ of the individual branch currents, the total current for this circuit must be _____ mA.

   Since the total power in a resistive circuit can be calculated as _____ times _____, then the total power dissipated by this circuit is _____ mW.

3. Calculate the individual power dissipations of the three branch resistances.

   P_1 = _____ P_3 = _____

   P_2 = _____

   Does $P_1 + P_2 + P_3$ equal the answer given for P_T in step 2? _____

   Which resistor dissipates the most power? _____ Is this the largest or the smallest value resistor in the circuit? _____

   Which resistor dissipates the least power? _____ Is this the largest or the smallest value resistor in the circuit? _____

   In conclusion, the smaller a branch resistance is in a parallel circuit, the (*lesser, greater*) _____ amount of power it will dissipate. The voltage through each

branch is equal and the current is _____ proportional to the branch resistance. Therefore V x I will be greater if the resistor is of _____ value.

4. Remove R_2 and replace it with a 10kΩ resistor. Complete the following table by measuring each branch current and calculating the individual power dissipations and the total circuit power. Keep the applied voltage at 12 volts.

V_A =	
I_1 =	
I_2 =	
I_3 =	
P_1 =	
P_2 =	
P_3 =	
P_T =	

When the resistance in one branch changed did it cause the power dissipated in that branch to change?

_____

When the resistance in the one branch changed did it cause the power dissipated through the unchanged resistive branches to change?

_____

When the resistance in the one branch changed did it cause the total power dissipated in the circuit to change?

_____

Parallel Circuits

Detecting an Open in a Parallel Circuit

Project 19

Project Objective:

- To provide experience with the change that occurs when an open develops in a parallel circuit.
- To verify that the total circuit current will decrease by the same amount that was passing through the defective branch prior to it becoming open.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 47kΩ, 100kΩ, 220kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 19-1.

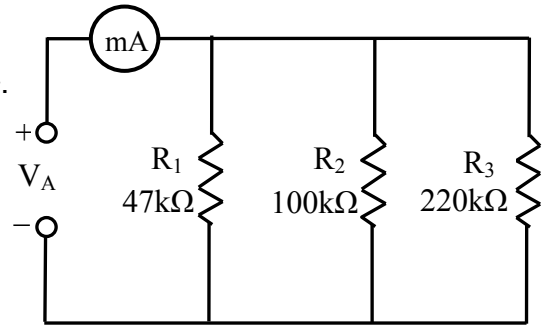


Figure 19-1

2. Apply 30 volts to the circuit. Measure the total circuit current and the individual branch currents. Calculate R_T.

   I_T = _____.

   R_T = _____.

   I_1 = _____.

   I_2 = _____.

   I_3 = _____.

   The total resistance is less than the _____ value resistance branch.

   a.) highest b.) lowest c.) both a & b

   The total circuit current is equal to the _____ of the branch currents.

3. Remove resistor R_1 to simulate an open in that particular branch. Keep the applied voltage at 30 volts and measure the total circuit current and the individual branch currents. Calculate R_T.

   I_T = _____. I_2 = _____.

   R_T = _____. I_3 = _____.

   I_1 = _____.

   If any branch of a parallel circuit becomes open, R_T will _____. Therefore,

   since the voltage remained the same, I_T will _____.

   Did the current through R_2 and R_3 change when R_1 became open? _____

   R_T increased because when R_1 became open there was one less _____ path.

   The current through the open branch decreased to _____ mA.

   When R_1 became open, what happened to the current through the unopened branches?

Did the voltage across all the branches change when R_1 became open? _____

4. Using the normal circuit condition values in step 2, calculate each branch power dissipation and the total circuit power dissipation.

   P_T = _____ P_2 = _____

   P_1 = _____ P_3 = _____

5. Calculate each branch power dissipation and the total circuit power dissipation using the values when R_1 was open in step 3.

   P_T = _____ P_2 = _____

   P_1 = _____ P_3 = _____

   When one branch of a parallel circuit becomes open, is the power dissipated by the other branches affected? _____. Is P_T affected? _____

   P_T will _____ by the same amount of power that was being dissipated by the opened branch before it became open.

Parallel Circuits

Detecting a Short in a Parallel Circuit

Project 20

Project Objective:

To provide experience with resistance changes that occur when a short develops in a parallel circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 47kΩ, 100kΩ, 220kΩ

Do not use the power supply for this project!

Experiment

1. Connect the circuit as shown in Figure 20-1.
2. Using an ohmmeter, measure between points A and B to find the total resistance of the circuit. **Remember, there is to be no power applied to the circuit when making resistance measurements!**

   R_T = _____.

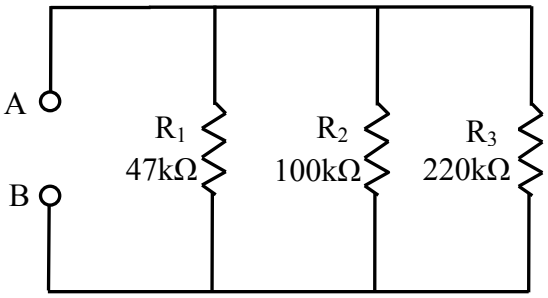


Figure 20-1

3. Simulate R_1 becoming shorted by removing it and replacing it with a jumper wire. Measure the new R_T and record the result below.

   New R_T = _____.

   When a branch of a parallel circuit is shorted, R_T (*increases, decreases*) _____

   to _____ Ω. Without connecting the power supply, assume there is 10v applied between points A and B. How much current would be going through R_2? _____.

   How much current would be going through R_3? _____.

   With the assumed 10v applied, what would the voltage reading be across R_2? _____

   Across R_3? _____.

   Assume there is 0.01Ω of resistance in the shorted circuit. Use the assumed 10v applied and calculate the circuit current using Ohm's Law.

   I_T = _____.

   Would this be enough current to blow the fuse on the power supply? _____

4. Remove the jumper wire and place R_1 back into the circuit. Now simulate a short in branch R_2 by replacing resistor R_2 with a jumper wire. Measure and record R_T again.

   R_T = _____.

   A short in any branch of a parallel circuit will cause R_T to _____ to _____ Ω.

   Does the current through the "un-shorted" branch increase or decrease? _____

Does the current through the “shorted” branch increase or decrease? _____

Does the voltage through all the branches increase or decrease? _____

If any one branch of a parallel circuit is shorted it appears that all the branches are shorted. Although only one branch contains the actual shorted element that causes the undesired low path of resistance nearly approaching _____ Ω.

Combination Circuits

Resistance in Series-Parallel Circuits

Project 21

Project Objective:

To verify series and parallel resistance rules as they apply to series-parallel combination circuits.

Items Needed:

- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 4 - 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 21-1.
2. Calculate the total circuit resistance from the resistor values given.

   R_T = _____.
3. Apply enough voltage to obtain a total circuit current of 1.2mA. Measure and record the following voltages.

   V_A = _____.

   V_1 = _____.

   V_2 = _____.

   V_3 = _____.

   V_4 = _____.

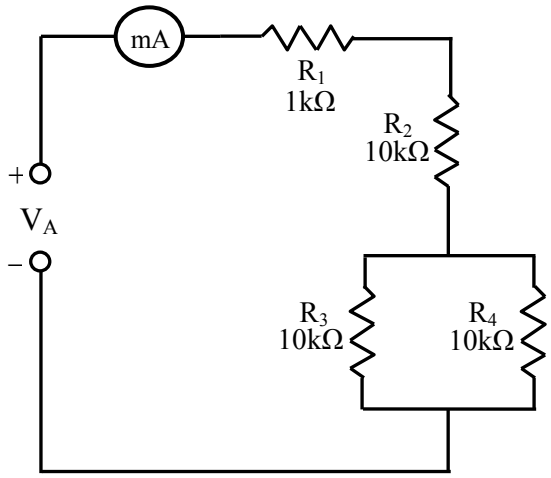


Figure 21-1

Since the applied voltage is _____ V and the total circuit current is _____ mA, then according to Ohm's Law the total resistance must be _____ Ω. Is this close to the result in step 1? _____

Which resistors in this circuit are in parallel? _____

Is the voltage the same across these resistors? _____

Which resistors are in series and carry I_T? _____

4. **Disconnect the power supply** and the ammeter from the circuit and measure the total resistance with an ohmmeter.

   R_T = _____.

   In conclusion, in series-parallel combination circuits, the total resistance equals the sum of all the components in _____ plus the equivalent resistance of parallel components whose combined resistance is effectively in _____ with the components in the main line.

5. Calculate what the total resistance of the circuit would be if a 10kΩ resistor (R_5) were added in parallel to R_2. Use Figure 21-2 as a reference.

   $R_{T\ calc}$ = _____.

6. Connect the circuit as described in step 5 and measure R_T. **Make sure there is no power applied to the circuit.**

   $R_{T\ meas}$ = _____.

   Briefly describe the process used to calculate R_T for this circuit.

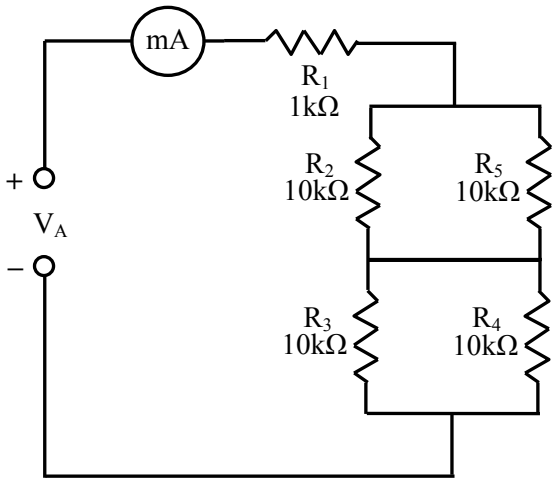


Figure 21-2

_____

_____

_____

_____

_____

Would R_T change if the jumper above R_3 and R_4 and below R_2 and R_5 were to be removed from the circuit? _____

Combination Circuits
Current in Series-Parallel Circuits

Project 22

Project Objective:

To better understand the characteristics of current flow in series-parallel combination circuits by combining both the series and parallel circuit analysis methods previously learned in the course.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 3.3kΩ, 4 - 10kΩ, 2 - 47kΩ, 100kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 22-1.
2. Connect the ammeter to read I_T and apply just enough voltage to have a total circuit current of 600μA. Measure all of the voltage drops and the current through each component. Record your results below.

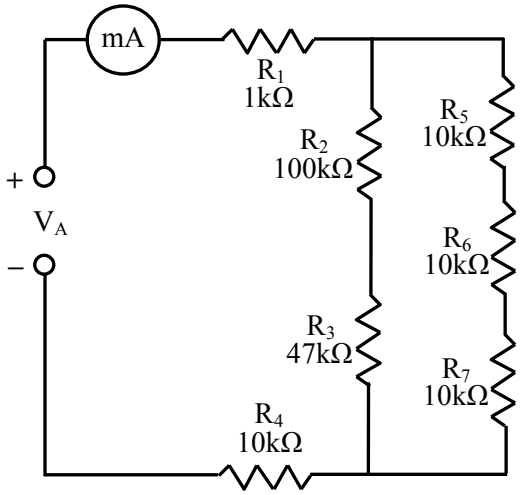


Figure 22-1

V_A = _____.

V_1 = _____.

V_2 = _____.

V_3 = _____.

V_4 = _____.

V_5 = _____.

V_6 = _____.

V_7 = _____.

I_1 = _____.

I_2 = _____.

I_3 = _____.

I_4 = _____.

I_5 = _____.

I_6 = _____.

I_7 = _____.

Which components have the total circuit current flowing through them? _____

What is the resistance of only the parallel portion of the circuit after it has been simplified?

_____

It should be noted that in series-parallel circuits, the current flow through a given component depends on where the component is located in the circuit. The series "portion" of the circuit can be solved by using the same rules as used in _____ circuits, and the parallel "portion" can be solved by using the rules for _____ circuits. The circuit can then be finalized by combining the results of both the series and the parallel portions of the circuit.

3. Predict what will happen to all the circuit currents if R_6 were changed to a 47kΩ resistor. Indicate below whether each current will *increase, decrease* or *stay the same*.

   I_1 will _____. I_5 will _____.

   I_2 will _____. I_6 will _____ .

   I_3 will _____. I_7 will _____.

   I_4 will _____. I_T will _____.

   Increasing the resistance value of any component in a series-parallel combination circuit will cause the total current to _____. This is true with not only combination circuits but for any circuit. It is possible for component currents to increase in a parallel circuit because of the changed resistance value. This is due to the fact that a larger percentage of the total current will pass through the unchanged parallel branch.

4. Verify your predictions in step 3 by replacing R_6 with a 47kΩ resistor. Measure all of the circuit voltage drops and currents using the same applied voltage used in step 2.

   V_1 = _____. I_1 = _____.

   V_2 = _____. I_2 = _____.

   V_3 = _____. I_3 = _____.

   V_4 = _____. I_4 = _____.

   V_5 = _____. I_5 = _____.

   V_6 = _____. I_6 = _____.

   V_7 = _____. I_7 = _____.

   V_A = _____. I_T = _____.

   Do these measurements agree with the predictions in step 3? _____

5. Change R_6 from the 47kΩ to a 3.3kΩ resistor. This resistor is less than the original 10kΩ used in step 2. Predict which currents will increase and which ones will decrease. Record your predictions below. After predicting, make measurements as needed to verify or correct your predictions.

   Which currents will increase? _____

   _____

   Which currents will decrease? _____

   _____

   Decreasing the resistance value of any component in a series-parallel combination circuit will cause the total current to _____. This is true with not only combination circuits but for any circuit. It is possible for a component current to decrease in a parallel circuit when the total circuit current is increased. This is because a smaller percentage of the total current will pass through the unchanged parallel branch.

Combination Circuits

Voltage in Series-Parallel Circuits

Project 23

Project Objective:

- To better understand the characteristics of voltage distribution in a series-parallel circuit by taking measurements and making observations.
- To verify that a component's voltage drop is affected by that component's value and location in a series-parallel circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 3 - 10kΩ, 18kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 23-1.

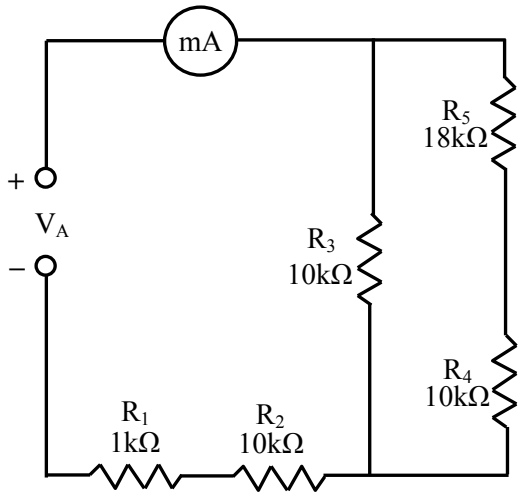


Figure 23-1

2. Assume there is a total current of 700μA. Calculate all of the circuit voltages and record the results below.

   V_1 = _____.

   V_2 = _____.

   V_3 = _____.

   V_4 = _____.

   V_5 = _____.

   What would the applied voltage need to be to obtain these results? _____.

3. Apply the correct amount of voltage to obtain 700μA of total circuit current. Measure all of the circuit voltages and record the results below.

   V_1 = _____. V_4 = _____.

   V_2 = _____. V_5 = _____.

   V_3 = _____. V_A = _____.

   Did the measurements confirm the calculations in step 2? _____

   Did the largest resistor have the largest voltage drop? _____ Why or why not?

   _____

   _____

   _____

   Which components does I_T pass through? _____

   The combined resistance of the parallel section can be considered to be in series with the

(*largest branch, main line*) _____ components.

4. Will V_3 increase or decrease if R_5 is replaced with a jumper wire? _____.
5. Make the circuit change suggested in step 4.

   Did V_3 change as predicted in step 4? _____

   When the resistance in a parallel branch is decreased, this causes the total circuit current to _____. This causes the voltage drops of the components that are in series with the main line to _____. Because of this, a lesser amount of applied voltage is dropped across R_3.

Combination Circuits

Power in a Series-Parallel Circuit

Project 24

Project Objective:

- To illustrate the power distribution characteristics of a combination circuit by making measurements and calculations.
- To verify that the electrical parameters of a series-parallel circuit are influenced by the "electrical location" rather than the physical location of a component.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 10kΩ, 18kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 24-1.
2. Apply the correct amount of voltage to obtain 1.2mA of total circuit current. Calculate R_T and V_A and record your results below.

   $R_{T\ calc}$ = _____.

   $V_{A\ calc}$ = _____.
3. Measure each individual voltage drop and calculate the power dissipated by each component in the circuit.

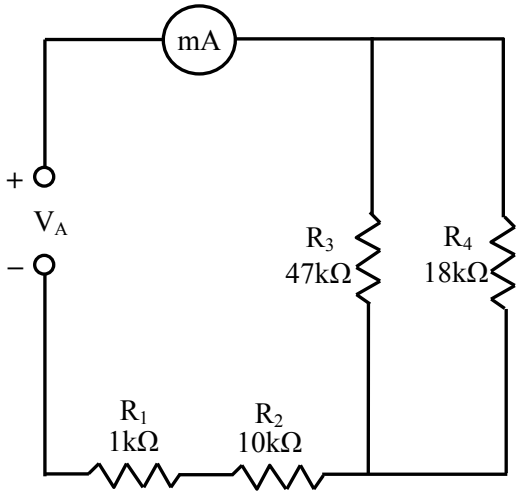


Figure 24-1

V_A = _____.

V_1 = _____.

V_2 = _____. P_1 = _____.

V_3 = _____. P_2 = _____.

V_4 = _____. P_3 = _____.

P_T = _____. P_4 = _____.

What two units are directly proportional to the power dissipated in this series-parallel circuit?

1. _____ 2. _____

Is this true with any circuit? _____

Do the components in the parallel portion of the circuit dissipate more or less power with a higher resistor value? _____

Do the components in the series portion of the circuit dissipate more or less power with a higher resistor value? _____

Which component in the circuit dissipated the most power? _____

Notice that this is not the largest resistance value in the circuit. Only in a simple series circuit the largest resistance value dissipates the most power. Also notice that it is not the smallest resistance value in the circuit. Only in a simple parallel circuit the smallest resistance value dissipates the most power. This proves that power distribution in a series-parallel circuit depends on the electrical _____ of the component being considered.

4. Swap R_3 and R_4. Use voltage measurements to determine if the powers dissipated by each of the resistances have changed.

   Are the results the same or different? _____

   Obviously the _____ location of the components is not important but the _____ location determines the distribution of power in a series-parallel combination circuit.

Combination Circuits

Detecting an open in a Series-Parallel Circuit

Project 25

Project Objective:

- To demonstrate the effects of an open occurring in both the series and parallel portions of a combination circuit.
- To observe what happens to the total circuit current when an open occurs in a series-parallel circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 3 - 10kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 25-1.
2. Apply the correct amount of voltage to obtain 1.2mA of total circuit current. Measure the circuit voltages and record them below.

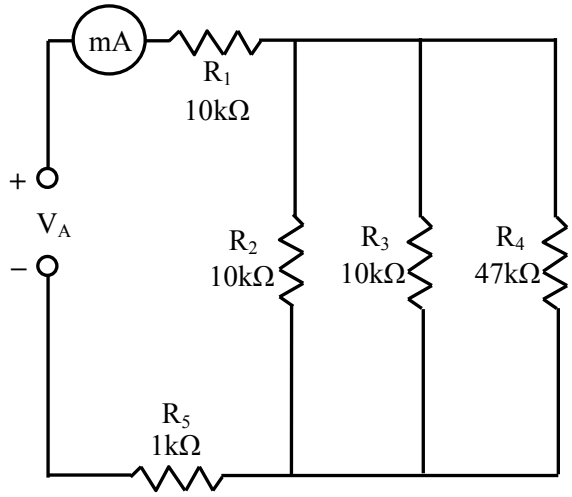


Figure 25-1

V_A = _____.

V_1 = _____.

V_2 = _____.

V_3 = _____.

V_4 = _____.

V_5 = _____.

3. Measure the current through each component.

I_T = _____. I_3 = _____.

I_1 = _____. I_4 = _____.

I_2 = _____. I_5 = _____.

Which resistances in this circuit does I_T flow through? _____ This is because these resistances are in _____ with the main line.

What resistances have the same voltage drop? _____ This is because these resistances are in _____ with the main line components.

4. Remove resistor R_5 from the circuit. This will simulate an "open" in the main line of the circuit. Measure and record the following circuit voltages.

V_A = _____. V_3 = _____.

V_1 = _____. V_4 = _____.

V_2 = _____. V_5 = *(across the open)* _____.

What happened to the voltage drops across all of the "good" components in the circuit?

_____

_____

The voltage drop across the "open" resistor is equal to the _____ voltage.

Explain what happens to I_T when an open occurs to a component that is in series with the source. _____

_____

5. Replace R_5. Now remove R_2 to simulate it becoming "open". Measure the circuit voltages and record them below.

V_A = _____. V_3 = _____.

V_1 = _____. V_4 = _____.

V_2 = *(across the open)* _____. V_5 = _____.

When compared to the values in step 2, what happened to the voltage drops across the components in series with the main line? _____

_____

When compared to the values in step 2, what happened to the voltage drops across the components directly in parallel with the open? _____

_____

What happened to I_T when compared to the calculated value in step 3? _____

_____

It does not matter whether an open occurs in the series or parallel portion of a combination circuit the total circuit resistance will always _____ and the total circuit current will _____.

Combination Circuits

Detecting a short in a Series-Parallel Circuit

Project 26

Project Objective:

- To demonstrate the effects of a short occurring in both the series and parallel portions of a combination circuit.
- To observe what happens to the total circuit current when a short occurs in a series-parallel circuit.

Items Needed:

- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 3 - 10kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 26-1.
2. Apply the correct amount of voltage to obtain 700 µA of total circuit current. Measure the circuit voltages and record them below.

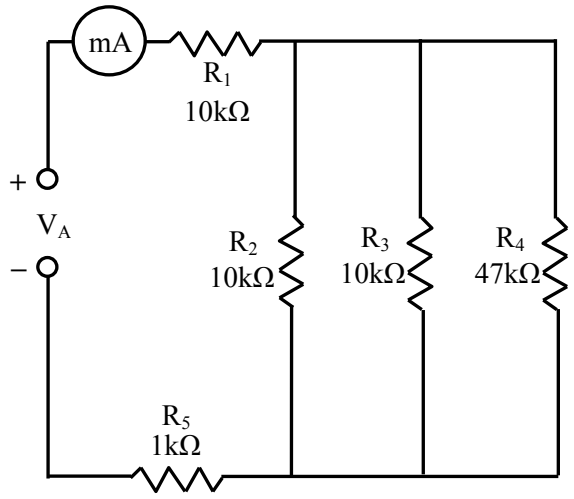


Figure 26-1

V_A = _____.

V_1 = _____.

V_2 = _____.

V_3 = _____.

V_4 = _____.

V_5 = _____.

3. Measure the current through each component.

I_T = _____. I_3 = _____.

I_1 = _____. I_4 = _____.

I_2 = _____. I_5 = _____.

In this circuit, I_T flows through _____ and _____.

The voltage drops of _____, _____ and _____

are the same because they are all in parallel to the main line components.

4. Simulate a short in R_1 by replacing it with a jumper wire. Measure and record the new voltages.

V_A = _____. V_3 = _____.

V_1= *(across the short)* _____. V_4 = _____.

V_2 = _____. V_5 = _____.

What happened to the voltage drops across all of the “un-shorted” components in the circuit?

_____

_____

The voltage drop across the shorted component equals _____.

What happens to I_T when a short occurs to a component that is in series with the main line components? _____

_____

5. Remove the jumper wire and replace R_1. Now simulate R_3 shorting out by replacing it with a jumper wire. Measure the new voltage drops and record your results below.

V_A = _____. V_3 = *(across the short)* _____.

V_1 = _____. V_4 = _____.

V_2 = _____. V_5 = _____.

Explain what happened to the voltage drops of the components that were in parallel with the short. _____

_____

What happened to the voltage drops of the components that were in series with the main line?

_____

_____

In conclusion, a short anywhere in the circuit will cause total circuit resistance to _____ therefore the total current will _____. This is true not only for series-parallel combination circuits, but for any circuit.

Circuit Troubleshooting Strategies

The job of a technician frequently entails "troubleshooting" malfunctioning circuits. Good troubleshooting skills, although highly demanded in industry, require a thorough understanding of the basic concepts, and a sense of creativity in applying a solution to correct the problem.

An essential skill to possess is a ready and intuitive understanding of how component faults affect circuits in different configurations.

Not every electrical circuit is similar in design. This means every malfunctioning circuit will require a different method and approach to finding and correcting the problem. This can be very overwhelming to the inexperienced troubleshooter who does not know where to even start. One thing is for certain; having a good understanding of the Ohm's Law relationships and the rules for series and parallel circuits is the first step to becoming a top-notch electrical troubleshooter.

Troubleshooting Series Circuits

Series circuits are usually the simplest type of circuit to troubleshoot because voltmeters can easily be used to locate voltage drops across specific components in the circuit.

As you learned earlier in this book, there are really only two types of faults in an electrical circuit, opens and shorts.

When using a voltmeter to check for opens and shorts in a series voltage divider circuit, try to think about the Ohm's Law relationship of voltage and resistance. The higher the resistance a component has, the higher the voltage drop across that component. Consequently, the lower the component resistance, the lower the voltage drop.

An open in the circuit will essentially be an infinite amount of resistance and will therefore have the maximum voltage drop or "source voltage" across it. Any other amount of resistance in the circuit will be irrelevant and will have no voltage drop. Even resistors with large values in the Mega-ohms cannot compare to an infinite amount of resistance.

In Figure T-1, resistor R_2 has become open. This creates a situation where electrical current is not flowing in the circuit. The voltage drop across the open will be equal to the full source voltage and the voltage drop across any other resistance in the circuit will be zero.

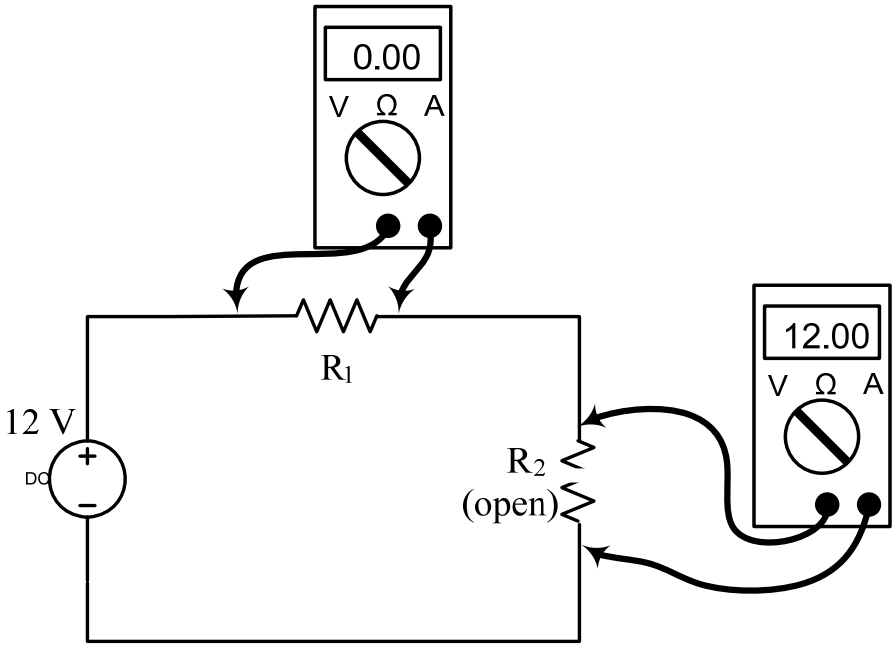


Figure T-1

Just as an open in a circuit will act as an infinite amount of resistance, a short in a circuit will act as a resistance value of zero. Since a small amount of resistance in a series circuit will have a small voltage drop, a resistance value of zero will have zero voltage drop. Think of it as measuring the voltage drop across the ends of a small piece of wire in a circuit.

In Figure T-2, R_1 has become shorted. This creates a situation where more current is flowing in the circuit than normal. There will be no voltage across the short at R_1 and the total source voltage will be measured across all the remaining components in the circuit.

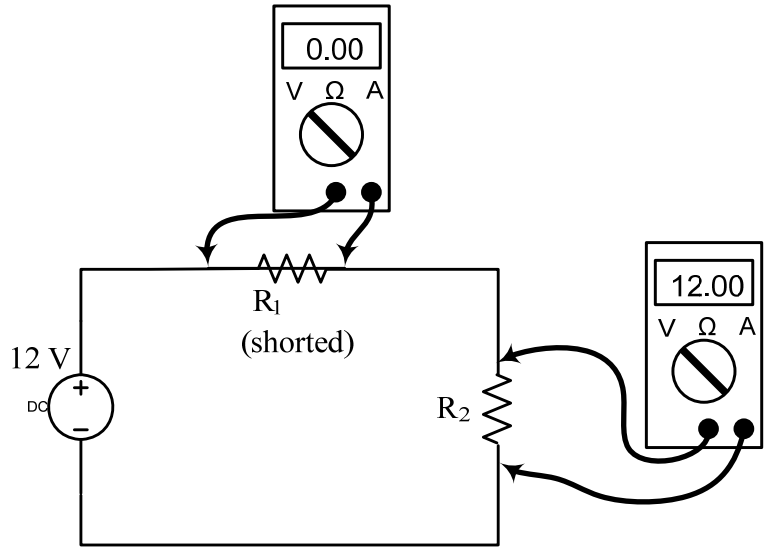


Figure T-2

Voltmeters are usually the desired tool for detecting problems in series circuits. If you noticed, however, the voltmeters in Figures T-1 and T-2 indicated the same voltage readings across the same components in both scenarios. If there were a third resistor connected in series, this would be a much easier circuit to troubleshoot because it would create a voltage divider that could be used to determine the open condition in Figure T-1 or the shorted condition in Figure T-2.

With this example circuit, an ammeter could be used in addition to the voltmeter to measure the circuit current. If a current is detected, then an open condition could not exist and the fault would most likely be the scenario in Figure T-2. If no current flow is detected in the circuit, then an open will exist somewhere and would suggest the scenario in Figure T-1.

An ohmmeter could also be used in addition to the voltmeter as long as the individual components or the power supply can be disconnected from the circuit.

Troubleshooting Parallel Circuits

Parallel circuits can be very challenging to troubleshoot. This is mainly because of the parallel voltage rule: *"The voltage drop across any parallel branch equals the applied voltage".* For example, in Figure T-3, R_2 has become open. If a voltmeter were used to troubleshoot this circuit, the source voltage would be detected across all three parallel branches and the technician would be unable to determine which of the three parallel branches is faulted.

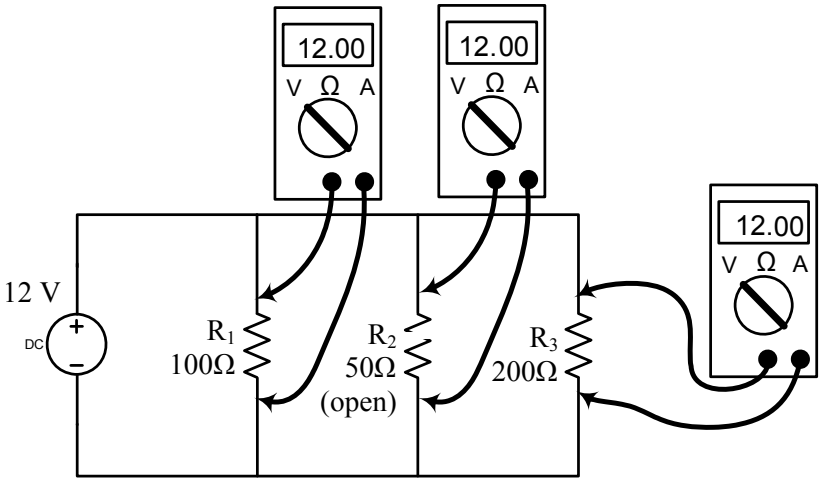


Figure T-3

If an ohmmeter were used to measure each resistive branch in the circuit (assuming the power supply is disconnected and the components cannot easily be removed from the circuit), the result would be the parallel combination of R_1 and R_3 across each parallel branch as shown in Figure T-4. In this example, the defective parallel branch is fairly easy to determine from the ohmmeter reading because of the parallel resistance rule: "*The total resistance of a parallel circuit is always less than the lowest-value resistive branch"*. The meter measures 66.67Ω which is higher than R_2's specified resistance of 50Ω. What if the fault were in one of the other branches? What if there were 20 resistive branches connected in parallel? This could be very difficult and time consuming to diagnose with an ohmmeter. There is a better way.

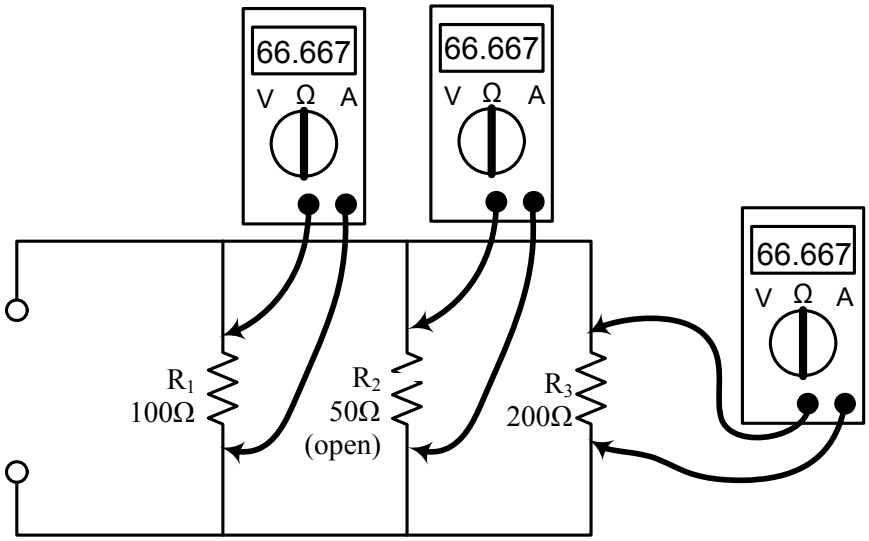


Figure T-4

If an open branch is suspected in a parallel circuit, the best method of locating the open branch is to begin by imagining the circuit has no faults and is functioning properly. Use Ohm's Law to calculate the total circuit current and the individual branch currents. In the example, the applied voltage is 12 volts. The branch currents can be calculated in the following manner:

$$I_1 = \frac{12v}{100\Omega} \qquad I_2 = \frac{12v}{50\Omega} \qquad I_3 = \frac{12v}{200\Omega}$$

$$I_1 = 120mA \;+\; I_2 = 240mA \;+\; I_3 = 60mA \;=\; I_T = 420mA$$

If the circuit were functioning properly, a circuit current of 420mA should be measured on its main line.

When the technician measures the current in the example circuit, only 180mA is detected. When the measured circuit current (180mA) is then subtracted from the calculated circuit current (420mA), there is a difference of 240mA. This is the same as the calculated current that should be going through branch R_2. This would then indicate that R_2 is open.

This method would obviously not work if each parallel branch had the same resistive value. If this is ever the case, begin by looking for signs of excessive heating or loose connections. The last resort would be to unsolder or disconnect one terminal of each resistor and individually check each component with an ohmmeter.

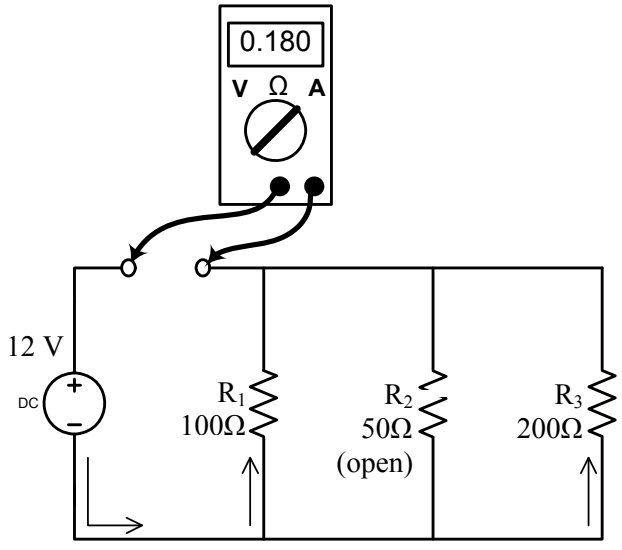


Figure T-5

If a short ever occurs in a parallel circuit, this usually spells disaster. Current will always take the path of least resistance. Since a short creates a very low resistance path for current, the total current will be very large and most likely trip the circuit breaker or blow a fuse. If no circuit protection device exists, a shorted parallel branch could very easily damage the power supply or even start an electrical fire.

Shorted parallel branches can be very difficult to locate in a circuit. This is because ohmmeters will indicate zero ohms of resistance across every resistive branch connected in parallel. The circuit also cannot be energized to take voltage and current readings because the circuit protection device will trip. Even if the power supply and protection device could handle the high current, chances are the meter will not.

The best way to diagnose a circuit such as this is to disconnect one end of each resistive component in the circuit and check for resistance with an ohmmeter.

Troubleshooting Combination Circuits

Since combination circuits contain both series and parallel portions, the rules for both series and parallel may apply depending on where the fault is located in the circuit.

Suppose we suspect the circuit in Figure T-6 may have a problem. Voltage readings across each component indicate a voltage drop across each series resistance as well as a voltage drop across the parallel resistances. Since each component has a voltage drop, we can determine that no shorted components exist in the circuit. Since the voltage drops across the components in the series portion of the circuit are all less than the source voltage, we can also conclude that the series portion of the circuit contains no opens.

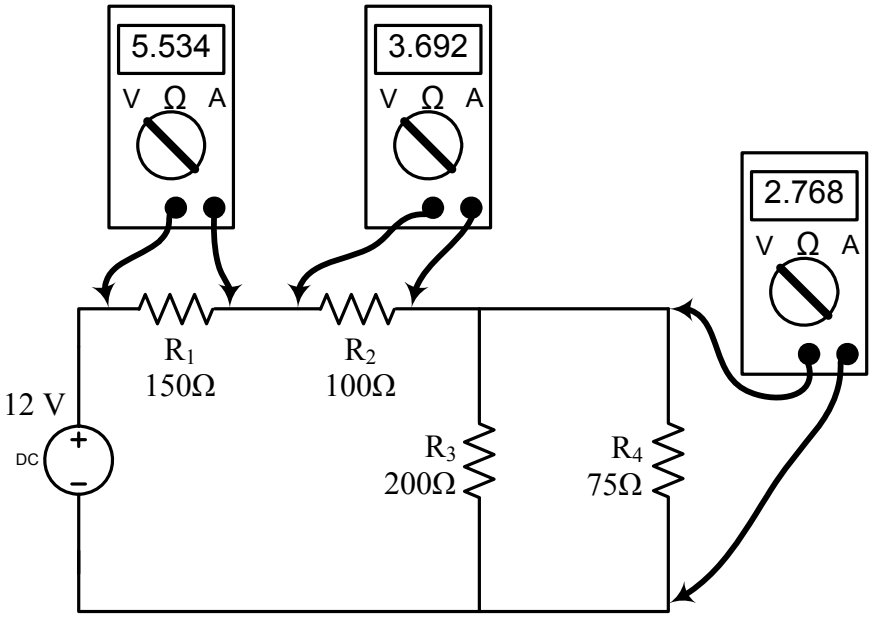


Figure T-6

So far this circuit appears to be functional, but there is one more possibility that could easily be overlooked.

An ammeter connected in series with the main current line indicates a total circuit current of 36.92mA. If the current values are calculated with the use of Ohm's Law, we find that the total circuit current should be 39.40mA.

$$R_T = \frac{1}{\frac{1}{200\Omega} + \frac{1}{75\Omega}} + 100\Omega + 150\Omega$$

$$R_T = 304.55\Omega$$

$$I_T = \frac{12v}{304.55\Omega} \qquad I_T = 39.40mA$$

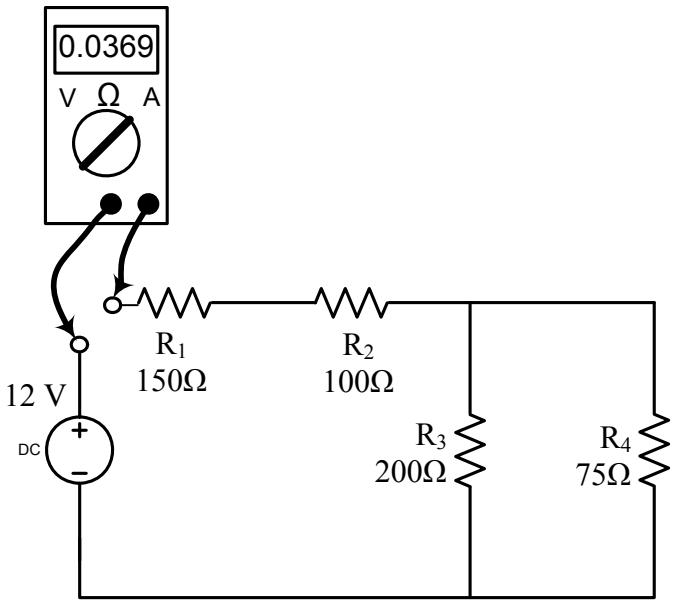


Figure T-7

The ammeter is definitely reading a lower value of current than it should be if this circuit was functioning properly. Since all other possibilities have been eliminated, there must be a missing current path somewhere in the parallel portion of the circuit. This would indicate either branch R_3 or R_4 is open.

To further narrow down the possibilities, the circuit can be recalculated assuming R_3 or R_4 is open. This can be done by redrawing and solving the circuit with the absence of one of the parallel resistances. We will begin by removing R_4 from the circuit.

When R_4 is removed from the circuit, the result is a three resistance series circuit that can easily be solved to determine I_T.

$$R_T = 150\Omega + 100\Omega + 200\Omega$$

$$R_T = 450\Omega$$

$$I_T = \frac{12v}{450\Omega} \qquad I_T = 26.67mA$$

With R_4 removed from the circuit to simulate an open, the calculated circuit current is 26.67mA. This does not match the measured 36.92mA.

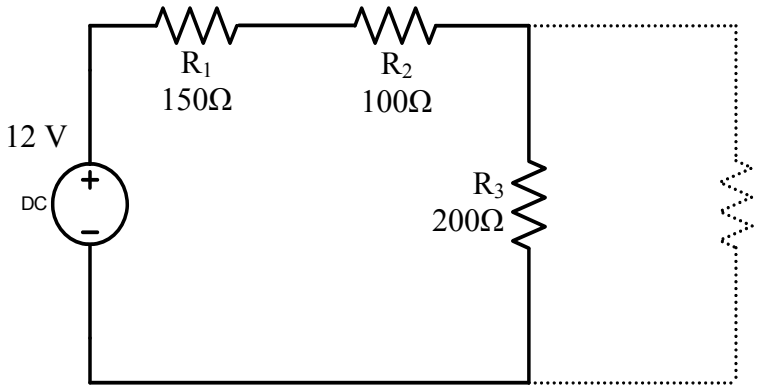


Figure T-8

From this we can determine that R_4 is not the open resistance and through the process of elimination R_3 is the only possible component remaining.

In order to verify our theory, the circuit can be drawn and re-calculated with the absence of R_3 in the same method.

$$R_T = 150\Omega + 100\Omega + 75\Omega$$

$$R_T = 325\Omega$$

$$I_T = \frac{12v}{325\Omega} \qquad I_T = 36.92mA$$

Sure enough the resultant calculated current when R_3 is removed from the circuit is 36.92mA, a match for the ammeter reading.

This verifies that resistive branch R_3 is the malfunctioning component in the circuit.

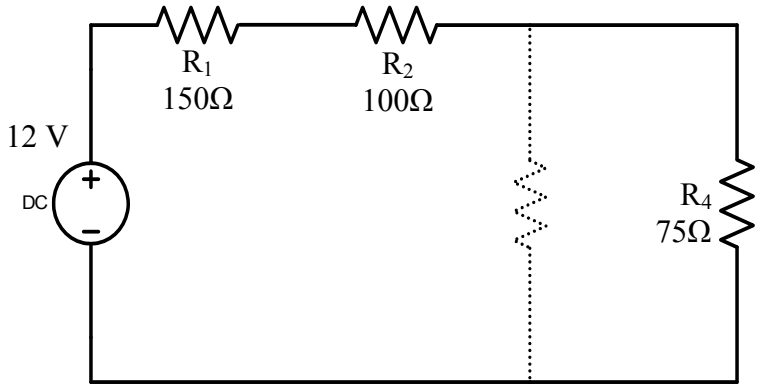


Figure T-9

Documentation Methods

Troubleshooting small 3 or 4 resistance circuits as in the previous examples do not take very many steps and are fairly easy to recall prior observations and conclusions. What if a technician were asked to troubleshoot a large electrical circuit with dozens of components and numerous connection points?

It is always wise to document each step when troubleshooting a circuit. This can be an extremely helpful resource for recalling prior measurements and observations gathered in the troubleshooting sequence. It can also be used as a reference for another technician who may have to troubleshoot the same circuit. A log of these troubleshooting documents can be recorded in a database to determine common faults and failures in the system.

Refer to the circuit in Figure T-10. The light bulb refuses to illuminate when the switch is closed. Suppose a technician were troubleshooting this circuit. See Figure T-11 for an example of how the technician records each of his steps. Notice the table is divided into two columns: Observations and Conclusions.

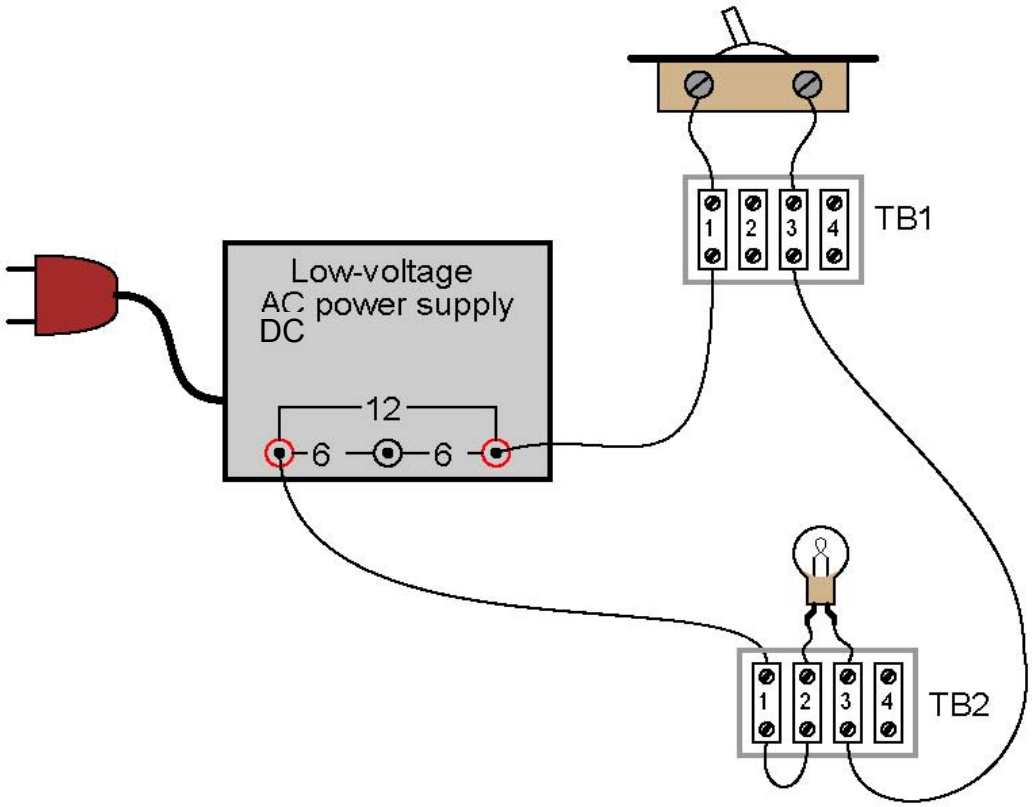


Figure T-10

Observations	Conclusions
Turned switch ON – no light	Definitely a problem in this circuit!
Measured 12 volts between terminal blocks TB1-1 and TB2-1	Power supply is functioning properly.
Measured no voltage across the light bulb (between TB2-2 and TB2-3)	Light bulb is not open, just not receiving any power.
Measured no voltage across closed switch (between TB1-1 and TB1-3)	Switch is good.
Measured no voltage between terminals TB1-3 and TB2-3	Wire between TB1-3 and TB2-3 is good
Measured 12 volts between terminals TB2-1 and TB2-2	Bad connection between those two terminals. Possibly an open wire or dirty connection between wire and terminal block.
Replaced wire between TB2-1 and TB2-2. Light bulb now works!	***Problem Solved!***

Figure T-11

Breadboard Circuits

Most electronics students gain hands-on experience with circuits by building them in temporary form on solderless breadboards. These boards are very convenient for lab use, as they allow students to quickly assemble and re-configure circuits using a wide variety of components.

There is much more to learning electronics than merely building circuits, though. A vital element of electronics education is learning how to diagnose faulty circuits through the use of test equipment.

Unfortunately, the same solderless breadboards that work so well for rapid circuit construction are rather poor for simulating circuit faults. It is very easy to see a component leg lifted to simulate an open, or a jumper wire across a component to simulate a short. In order for the troubleshooting exercises to be valid, students should not be able to inspect the circuits in any way but by using test equipment.

The concept of these exercises works on the principle of taking measurements between test points on a circuit board. Production circuit boards are commonly equipped with metal "test points" used for the connection of test equipment. These test points are especially valuable when the boards are coated with a protective barrier, since the coating prevents direct connection to the component terminals. In cases like this, test points are the only contact points through which circuit signals may be measured.

In the following exercises, student access is limited to their faulted breadboard circuits in the same way, with the breadboard hidden and the test points located some distance away from it. This may be done by using a “testing jig” constructed of a long cable containing several wires and a terminal block.

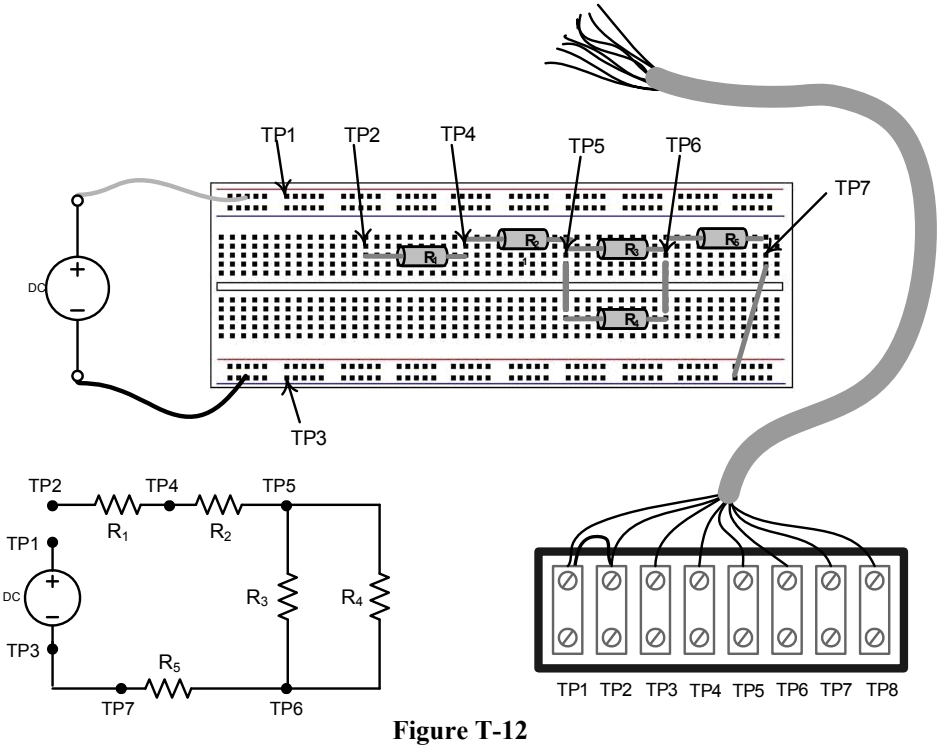


Figure T-12

Each student is to construct the circuit specified for each exercise, making sure the circuit is completely functional. The “testing jig” must then be inserted into the circuit in order for measurements to be taken at the terminal strip. It is important that the correct colored wires be inserted for their corresponding test points.

Once the circuit is constructed and fully functional with the testing jig in place, have a lab partner or instructor create a fault somewhere in the circuit. This is easily accomplished by lifting a leg or removing a component to simulate an open, or inserting a jumper wire across a component to simulate a short. Once the fault is in place, cover the circuit with something such as a piece of paper so the circuit cannot be visually inspected.

The student may then begin troubleshooting the circuit using only a voltmeter or ammeter (**no ohmmeters),** the connected terminal block on the testing jig, and a circuit schematic. Each step in the troubleshooting sequence must be documented on the "Observations and Conclusions Table" provided for each exercise.

When finished with the exercises, design your own circuits and have a lab partner troubleshoot them.

When designing a circuit for troubleshooting, it is common practice to insert test-points so that voltage readings can be taken across each component in the circuit. It is also ideal for the troubleshooter to have the ability to measure circuit current. Be sure to design the circuit in such a way that current can be measured by simply removing the jumper wire connecting terminals 1 and 2 on the terminal block and inserting the ammeter leads in its place as shown in Figure T-14.

When generating a fault on a lab partner's circuit, make sure a resistance still exists in the circuit. Failure to do this will create a dead short and possibly damage the power supply and test equipment.

Complete the table below by assigning the correct colored wire to each test point. Use a troubleshooting jig along with the illustration in Figure T-12 as a reference

Wire Color	Test Point	Connect to:
	TP1	positive power supply output (+V)
	TP2	positive supply to circuit (ammeter connection point)
	TP3	ground
	TP4	voltage test point
	TP5	voltage test point
	TP6	voltage test point
	TP7	voltage test point
	TP8	voltage test point

Figure T-13

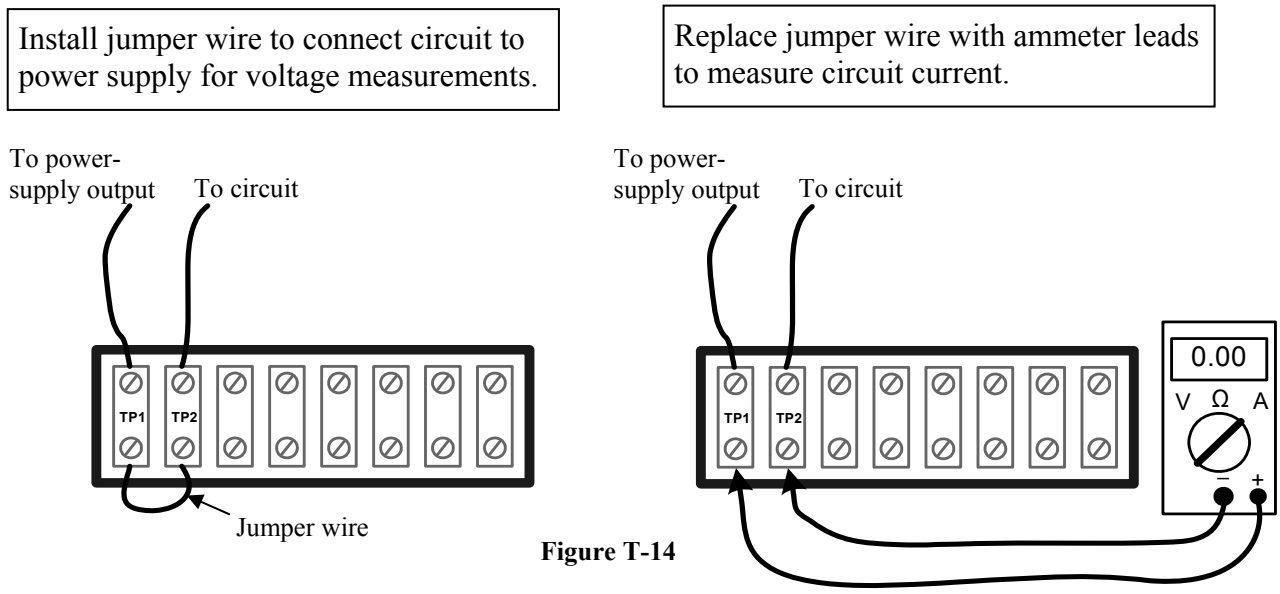


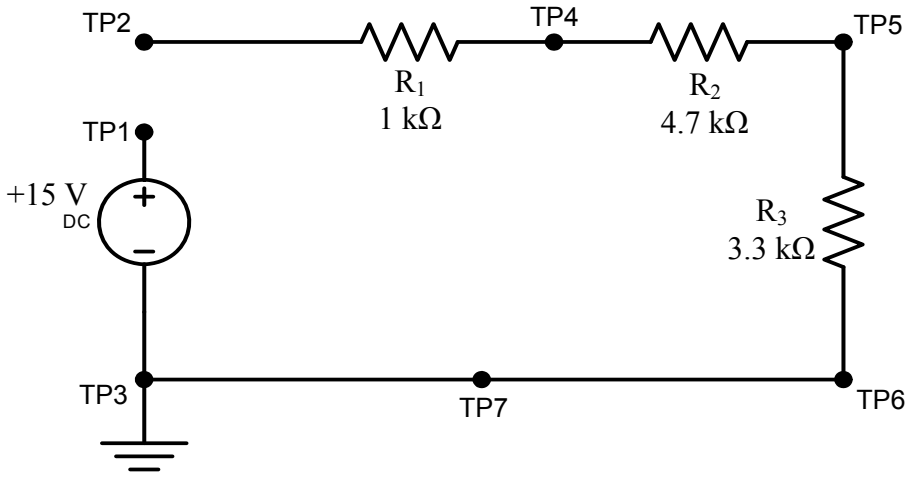
Figure T-14

Troubleshooting Exercise 1

Construct the following circuit on a solderless breadboard. Connect the testing jig according to the test points (TP's) in the schematic diagram. Make sure the correct TP wires are used. You may refer to the table on the previous page.

When finished, have your lab partner or instructor create a fault in the circuit.

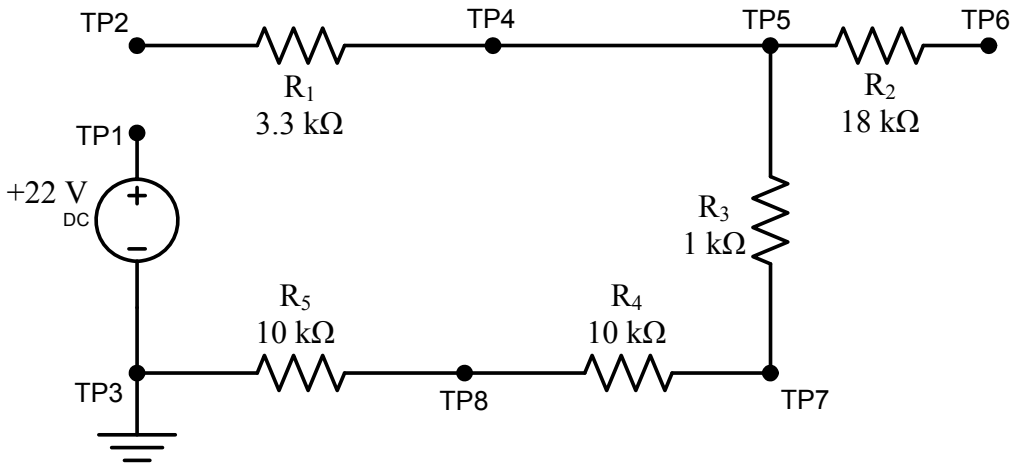
While troubleshooting the circuit, you may not view the breadboard connections. You may use either a voltmeter or ammeter (no ohmmeters) to take measurements from the terminal block on the testing jig. Record each step in the troubleshooting process on the "Observations and Conclusions Table" for this exercise.



Observations	Conclusions

Troubleshooting Exercise 2

Construct and troubleshoot the following circuit as in the previous exercise. Record your observations and conclusions in the table below.

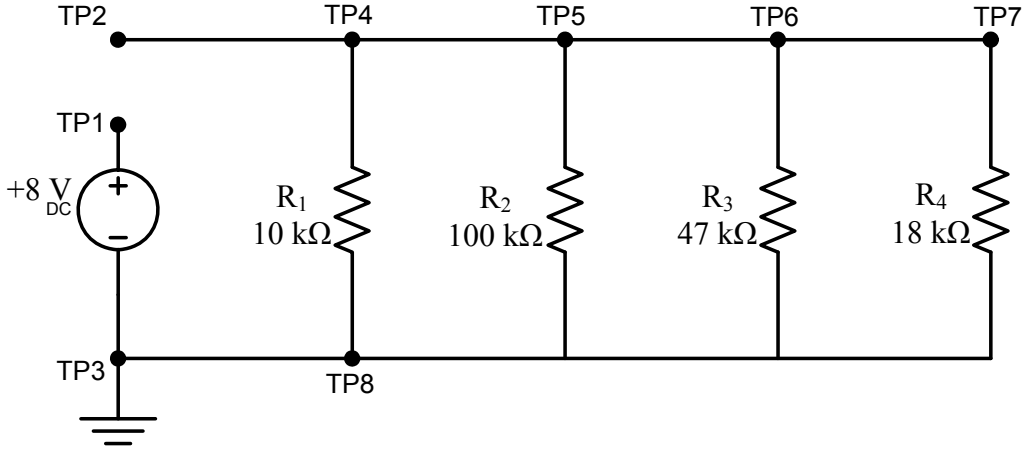


Observations	Conclusions

Troubleshooting Exercise 3

Construct and troubleshoot the following circuit. Record your observations and conclusions below.

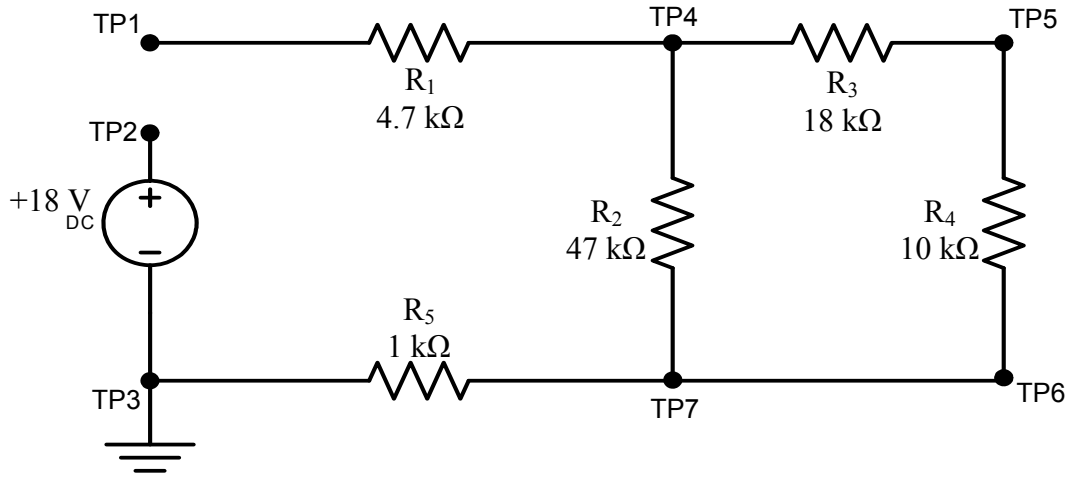
WARNING: Do not simulate a short anywhere in this circuit! Doing so could damage the power supply and/or test equipment. There must be a resistance in the circuit at all times!



Observations	Conclusions

Troubleshooting Exercise 4

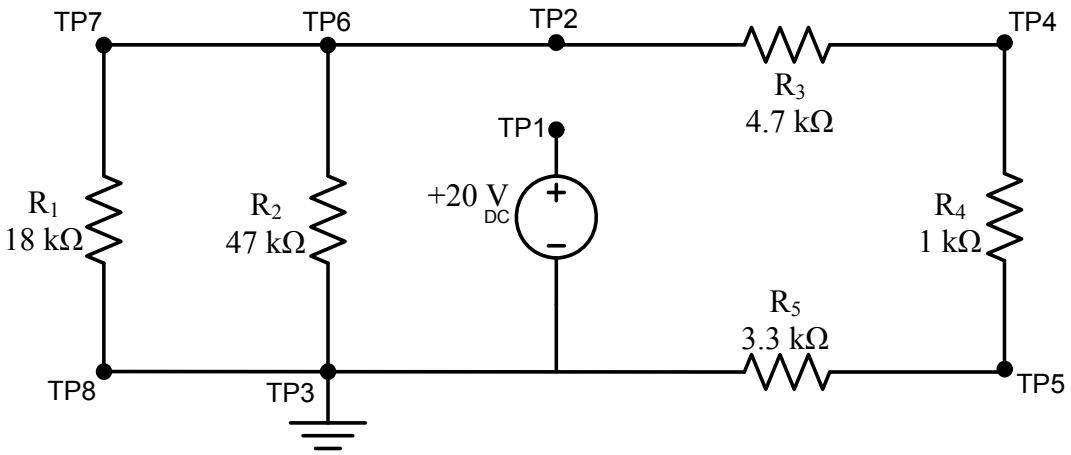
Construct and troubleshoot the following circuit. Record your observations and conclusions below.



Observations	Conclusions

Troubleshooting Exercise 5

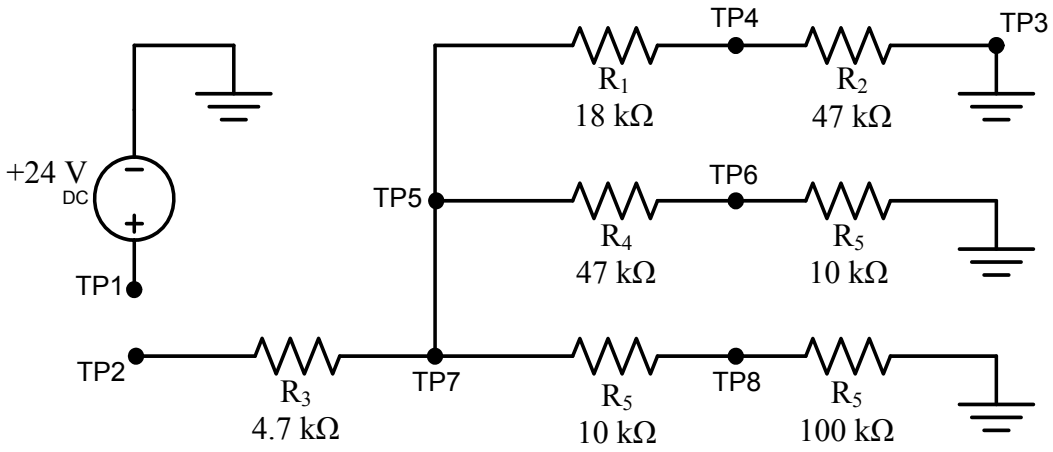
Construct and troubleshoot the following circuit. Record your observations and conclusions below.



Observations	Conclusions

Troubleshooting Exercise 6

Construct and troubleshoot the following circuit. Record your observations and conclusions below.



Observations	Conclusions

Design your own circuit here:

Observations	Conclusions

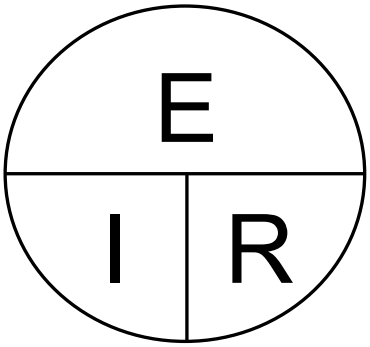
Design your own circuit here:

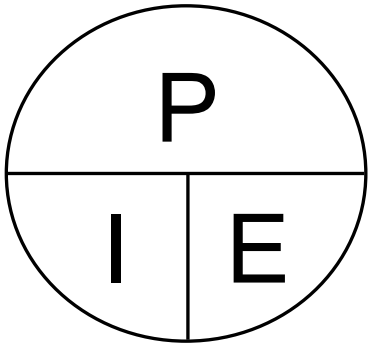
Observations	Conclusions

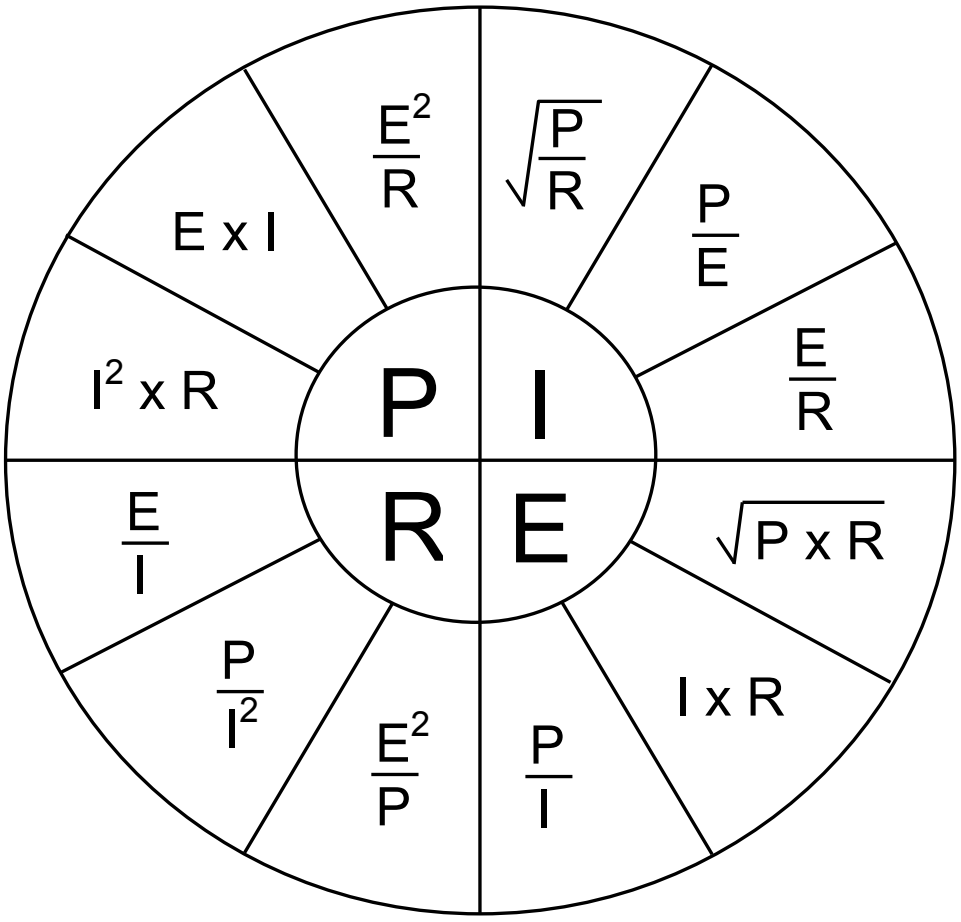
Design your own circuit here:

Observations	Conclusions

Formula Wheels







Notes:

Notes:

Instructor Sign-off sheet Student Name:

Project Number	Project Name	Instructor Initial	Date
Project 1	Voltmeters		
Project 2	Ammeters		
Project 3	Ohmmeters		
Project 4	Relationship of I and V with a Constant R		
Project 5	Relationship of I and R with a Constant V		
Project 6	Relationship of Power to V with a Constant R		
Project 7	Relationship of Power to I with a Constant R		
Project 8	Resistor Color Codes		
Project 9	Resistance in Series Circuits		
Project 10	Current Flow in Series Circuits		
Project 11	Voltage in Series Circuits		
Project 12	Power in a Series Circuit		
Project 13	Detecting an Open in a Series Circuit		
Project 14	Detecting a Short in a Series Circuit		
Project 15	Resistance in Parallel Circuits		
Project 16	Current Flow in Parallel Circuits		
Project 17	Voltage in Parallel Circuits		
Project 18	Power in a Parallel Circuit		
Project 19	Detecting an Open in a Parallel Circuit		
Project 20	Detecting a Short in a Parallel Circuit		
Project 21	Resistance in Series-Parallel Circuits		
Project 22	Current in Series-Parallel Circuits		
Project 23	Voltage in Series-Parallel Circuits		
Project 24	Power in a Series-Parallel Circuit		
Project 25	Detecting an Open in a Series-Parallel Circuit		
Project 26	Detecting a Short in a Series-Parallel Circuit		
	Troubleshooting Exercise 1		
	Troubleshooting Exercise 2		
	Troubleshooting Exercise 3		
	Troubleshooting Exercise 4		
	Troubleshooting Exercise 5		
	Troubleshooting Exercise 6		